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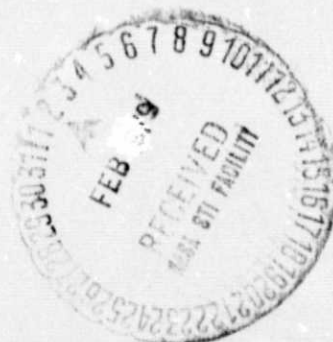
CSSL 03B G3/92

(NASA-CR-158069) RESEARCH ON SOLAR-WIND AND
MAGNETOSPHERIC ELECTRIC FIELDS AND PLASMAS
Final Report, 30 Sep. 1977 - 30 Nov. 1978
(Texas Univ. at San Antonio.) 47 p HC

A03/MF A01

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NASA, Goddard Space Flight Center
Grant No. NSG 5214



I. Summary of Research Project.

Research performed under this grant sought to determine the role of the interplanetary magnetic field in controlling (1) particle acceleration processes in the earth's polar cap; (2) plasma convection patterns at high latitudes; and, (3) the topology of magnetic field lines in the earth's polar cusps. The results of this research appear in papers that have been submitted for publication in the Journal of Geophysical Research, Geophysical Research Letters, and Space Science Reviews. Two final papers are still under preparation and will be submitted to the Journal of Geophysical Research in March, 1979.

The research involved the analysis of data from the Low Energy Electron Experiment and the Retarding Potential Analyzer/Drift Meter Experiment on Atmosphere Explorers C and D, along with magnetic field data from the interplanetary spacecraft Imp J. A brief summary of the results appears below, while the complete bibliography is listed in Section II. Several preprints are also attached, while reprints of published papers will be submitted when they are available.

The primary result of the study on polar-cap particle acceleration regions was that they tend to occur in only one polar cap at a time, and that they occur in the hemisphere for which the magnetospheric tail-lobe field lines have solar-magnetospheric x components that are antiparallel to those of the interplanetary and tail-lobe magnetic field. This result suggests strongly that merging between interplanetary and tail-lobe magnetic field lines is involved in the acceleration process. The complete lack of energetic positive ions in the polar cap acceleration regions suggests that they are the sites of strong field-aligned (or Birkeland) currents. This suggestion is confirmed by the convection irregularities which are observed in their vicinity by the AE RPA/Drift Meter experiment. These results are being described comprehensively in a paper entitled "Polar Cap Electron Acceleration Regions," which is soon to be submitted to the Journal of Geophysical Research. Preliminary results have been included in the paper entitled "IMF Changes and Polar-Cap Electric Fields and Currents," which is being submitted to Space Science Reviews in January, 1979.

The studies of high-latitude plasma convection and of the topology of magnetic field lines in the polar cusps are being reported together in a paper to be submitted to the Journal of Geophysical Research. Preliminary results have been reported in papers entitled "Effects of the Interplanetary Magnetic Field on the Auroral Oval and Plasmapause" submitted to Space Science Reviews in July, 1978), "IMF Changes and Polar Cap Electric Fields and Currents" (to be submitted to Space Science Reviews in January 1979), and "Dayside Auroral Arcs and Convection" (Geophys. Res. Lett., 5, 391, 1978). The results of these studies were that southward-directed interplanetary magnetic fields give rise to broad convection "throats" (as described by Heelis, Hanson, and Burch in J. Geophys. Res., 81, 3803, 1976) which cover several hours of local time across the dayside cleft. Under such conditions, solar-wind plasma is channeled efficiently through the polar cusps to populate the plasma mantle and dayside boundary layer. On the other hand, the appearance of strong northward components in the interplanetary magnetic field result in a very constricted throat, resulting in inefficient plasma entry at the cusps by diffusion processes.

II. Bibliography.

Research paper prepared under this grant include the following:

1. Burch, J. L., and Winningham, J. D., Relationships Between Particle Precipitation and Auroral Forms, in press, Journal of Geomagnetism and Geoelectricity, 1978.
2. Burch, J. L., and Heelis, R. A., Comment on paper entitled "Correlated Electric Field and Low-Energy Electron Measurements in the Low-Altitude Polar Cusp" by P. M. Kintner, K. L. Ackerson, D. A. Gurnett, and L. A. Frank, submitted to J. Geophys. Res., 1978.
3. Reiff, P. H., Burch, J. L., and Heelis, R. A., Dayside Auroral Arcs and Convection, Geophys. Res. Lett., 5, 391, 1978.
4. Burch, J. L., Effects of the Interplanetary Magnetic Field on the Auroral Oval and Plasmapause, Space Sci. Rev., in press, 1978.
5. Burch, J. L., and Heelis, R. A., IMF Changes and Polar-Cap Electric Fields and Currents, submitted to Space Sci. Rev., January, 1979.
6. Burch, J. L., Fields, S. A., and Heelis, R. A., Polar-Cap Electron Acceleration Regions, to be submitted to J. Geophys. Res., March, 1979.
7. Burch, J. L., Reiff, P. H., and Heelis, R. A., The Topology of Polar-Cusp Magnetic Field Lines, to be submitted to J. Geophys. Res., March, 1979.

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DAYSIDE AURORAL ARCS AND CONVECTION

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Abstract. Recent DMSP and ISIS dayside auroral observations show two striking features: a lack of visible auroral arcs near noon and occasional fan shaped arcs radiating away from noon on both the morning and afternoon sides of the auroral oval. We present a simple model which includes these two features as a consequence of the dayside convection pattern of Heelis et al. (1976). The model may be testable in the near future with simultaneous convection, current and auroral light data.

Introduction

The signature of the magnetospheric convection in the ionospheric polar cap is primarily antisunward flow, with a return sunward flow at lower latitudes on both the dawn and dusk sides (Heppner, 1972; Gurnett and Frank, 1973), corresponding to the familiar double-cell convection pattern (e.g., Cauffman and Gurnett, 1972). Recent 3-dimensional flow measurements (Heelis et al., 1976) have shown that the antisunward flow near noon is not uniform: the flow (or, equivalently, the cross-polar cap potential drop) is concentrated into a narrow "throat" region near local magnetic noon. Away from local noon, the boundary between sunward and antisunward convection is a sharp tangential discontinuity (shear reversal), whereas near local noon, the "boundary" is harder to define, since the flow paths display a rotational reversal.

In this letter we investigate the suggestion (Peiff et al., 1976) that this nonuniform flow pattern may produce visible signatures in the dayside auroral morphology.

The Model

Consider an infinitely long straight boundary where the $E \times B$ drift velocity undergoes a simple shear reversal (Figure 1a). In this case, the electric field on either side points toward the boundary, as occurs at the afternoon polar-cap boundary. The ionospheric Pedersen currents, therefore, also point toward the boundary from both sides. Current continuity ($\nabla_{\perp} \cdot \mathbf{j}_{\perp} = j_z$) requires a net upward Birkeland current at the boundary (e.g., Wolf, 1975; Yasuhara and Akasofu, 1977; Postoker and Bostrom, 1976, and references therein). For the definition of the

magnetic coordinate system, see Figure 1. Note that the requirement for an upward current is inescapable, no matter how the conductivity may change across the boundary.

Field-aligned currents are required along any boundary where the horizontal ionospheric current diverges. This divergence may be due either to a change in conductivity with a constant electric field (Figure 1b), or to a change in electric field (and flow velocity) with a constant conductivity (Figure 1c), or some combination of the two. In either case, we expect the boundary to be roughly flow-aligned. For example, enhanced conductivity may arise from a region of enhanced particle precipitation, which would be convected along flow lines.

The above model is clearly an oversimplification both in its geometry and in its neglect of ionospheric Hall currents. More complete models have been employed by Yasuhara et al. (1975), Sato (1976), and Yasuhara and Akasofu (1977) to calculate ionospheric electric fields from an average Birkeland current system as deduced from Triad data (Zmuda and Armstrong, 1974).

Our simple model, however, is sufficient to predict the location and direction of large-scale Birkeland currents in an idealized representation of an afternoon convection region (Figure 2). Guided by the results of Heelis et al. (1976), we have made the flow pattern not only converge near noon, but also show irregularities in flow velocities (as indicated by the spacing of the flow lines). For this simple example, we assume that the conductivity is roughly uniform within (separately) the sunward flow region and the antisunward flow region. We find sheets of field-aligned currents, both into (x's) and out of (dots) the ionosphere. The line (a) corresponds to the convection reversal, where the most intense upward currents are expected. The lines (b) and (c) also indicate upward currents (their strength depending on the local conductivity), and lines (d), (e), and (f) indicate downward currents. The more discontinuities there are in the flow velocity or conductivity, the more such current sheets will exist. Two distinguishing features of these current sheets are that (1) they appear to radiate from near noon and (2) they are absent or weaker just at noon. The current sheets (a-d) should correspond to the "Region 1" currents of Iijima and Potemra (1976a,b); sheet (e) corresponds to "Region 2" currents and sheet (f) to "Cusp Region" currents.

The remaining step of logic is to associate

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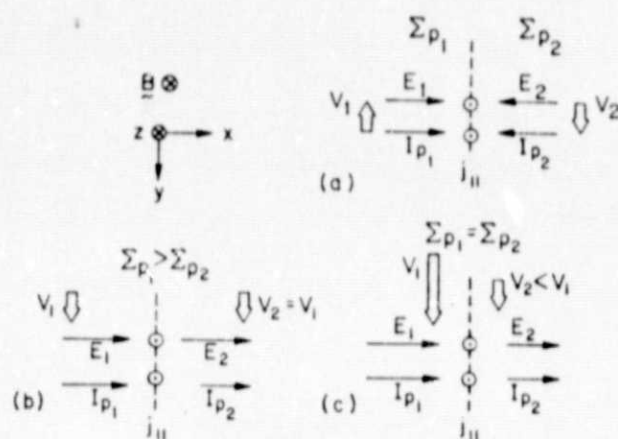


Fig. 1. Simple instances in which Birkeland currents are required for current continuity.

- (a) Reversal in convection electric field.
- (b) Discontinuity in ionospheric height-integrated Pedersen conductivity,
- (c) Discontinuity in flow velocity.

The NP indicates the north invariant pole; 1200 and 1800 MLT lines are shown.

sheets of upward Birkeland current with auroral arcs. For this model this is explicitly an assumption; however, this association has been demonstrated both on a small (km) scale (e.g. Casserly and Cloutier, 1975) and on a large (tens of km) scale (Kamide and Akasofu, 1976). We assume that arcs are not associated with downward current sheets, unless a weaker upward sheet is imbedded within them. Finally, we assume that the brightness of the arc increases with increasing current intensity.

The morning side can be treated in a similar way; just rotate the figure about the earth-sun line. Upward currents become downward, and vice versa. Two fundamental differences occur: (1) the most intense current sheet again occurs at the polar cap convection boundary (a), but this current is now downward and therefore should not necessarily be associated with visible arcs. (2) There are two upward current regions: the equatorward edge of the sunward flow region (sheet f) and the poleward edge of the antisunward flow region (sheet e). Unlike sheet (a) these other two sheets may not be required by the flow geometry and may be diffuse; nevertheless, they are likely to occur.

For this example, then, we would predict arcs at sheets (a, b, and c) on the afternoon side and at sheets (d, e, and f) on the morning side, with the most intense arc along sheet (a) in the afternoon.

Generalizing these results, we predict:

(1) No arcs, or only weaker sun-aligned arcs, just at noon. This feature is confirmed by DMSP photographs (Snyder and Akasofu, 1976; Dandekar and Pike, 1977), and in the 5577 Å data of the ISIS scanning auroral photometer (Cogger et al., 1978), all of whom saw a minimum in auroral emissions near noon. On the other hand, Shepherd et al. (1976) reported a noontime enhancement in 6300 Å emissions. Taken together, this implies that the 5577/6300 ratio is lower in the gap than in the neighboring

auroral zone; thus, the average energy of electrons precipitating near noon is lower (Rees and Luckey, 1974). This is essentially the same result as that of McIlarmid et al. (1976) and Potemra et al. (1977). These two studies showed from particle data that the near-noon cusp electrons are considerably cooler than those on the morning and afternoon sides. Potemra et al. (1977) associated this afternoon energetic electron precipitation with the region 1 field-aligned current region, as do we. A noontime gap in KeV ion and electron precipitation can also be seen in the data presented by Riedler and Borg (1972).

(2) The dayside aurora can assume fan shaped structures, with the arcs emanating from roughly 1100 MLT toward the morning side, and/or from roughly 1300 MLT toward the evening side. The fan shape results from multiple convection irregularities, and is therefore likely to be an intermittent phenomenon. We predict that these arcs are roughly flow-aligned; thus, the arcs bear striking similarity to the inferred flow pattern of Heelis et al. (1976). This feature is confirmed by DMSP photographs. Figure 3 is one of the first dayside auroral photographs published, by Snyder and Akasofu (1976, their Figure 4). It shows: (1) a noticeable gap, or absence of arcs, near noon, and (2) the fan-shaped structures, stronger on the afternoon side but still discernable on the morning side (note that this is a southern hemisphere pass, so that the afternoon side is on the right). No fan arcs have been published by ISIS; however, they have been observed occasionally (Anger, private communication, 1978).

(3) The most intense upward currents (and therefore, the brightest arcs) should occur on the convection reversal (sheet a) in the afternoon. This is confirmed by Cogger et al. (1977), who report a 5577 Å enhancement in the 14 to 16 MLT sector.

(4) The upward field-aligned currents on the

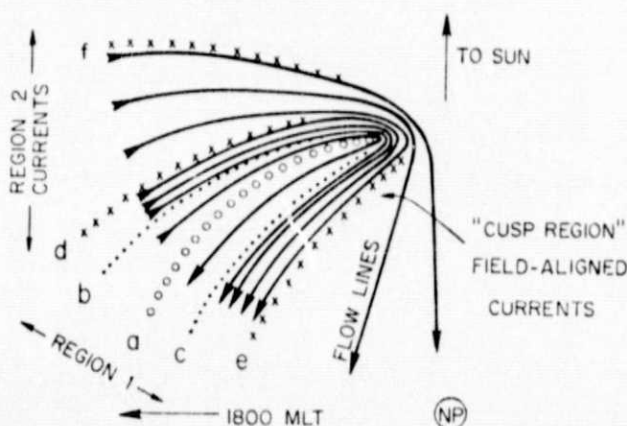


Fig. 2. Sketch of a typical "throat" convection geometry, with a flow discontinuities and resultant Birkeland currents. Lines of dots indicate downward currents. Possible associations with "Region 1", "Region 2", and "Cusp Region" field-aligned current regimes (Iijima and Potemra, 1976a,b) are shown.

morning side flow principally in the equatorward (sheet f) and poleward (sheet e) edges of the flow patterns. Thus the arcs on the morning side should generally span a wider range of latitudes than on the afternoon side. In particular, the most poleward sheet (e), is an upward current only on the morning side. The arc associated with this sheet has the greatest chance of extending past the terminator to become a "sun-aligned arc", and indeed one such arc can be seen in Figure 2 of Snyder and Akasofu (1976). This feature is confirmed by Ismail et al. (1977), who report that sun-aligned arcs are twice as frequent on the morning side than on the evening side.

(5) We note that in this model the most poleward currents (e) separate the faster flow at the edges of the polar cap from the slower flow near the center. Therefore, these currents should be stronger on the side where the convective flow is stronger: e.g., for the Northern hemisphere, the afternoon (morning) side of the polar cap for negative (positive) B_y of the interplanetary magnetic field, and the

opposite side in the southern hemisphere (Heppner, 1972). Thus it is not surprising that Iijima and Potemra (1976b) did not find a correlation of cusp current intensity with E_z , since they did not distinguish which side of the cusp they were on.

(6) Finally, we predict that the overall pattern of sheet currents near noon should resemble the convection pattern. Iijima and Potemra (1976b, Figure 3) show a series of line segments representing orientations of current sheets observed by Triad. The overall pattern of current sheet orientations is not compelling evidence, but is not inconsistent with the picture presented here.

Conclusions

Both the fan-shaped dayside aurora and the noontime auroral gap can be considered as simple consequences of the "throat" convection geometry of Heelis et al. (1976). These fan arcs can extend well into the polar cap (predominantly on the morning side), becoming "sun aligned" arcs on the nightside. Thus "sun-aligned arcs" might more reasonably be called "flow-aligned arcs". This conclusion is consistent with the data of Meng and Akasofu (1976), who showed polar cap arcs turning near midnight, thus possibly also flow-aligned.

We predict that the intensity of the "cusp region" field-aligned currents should be positively correlated with the strength of the ionospheric convection. Thus the cusp-region currents should be stronger on the afternoon (morning) side in the Northern (Southern) polar cap for an "toward" sector of the interplanetary magnetic field.

Naturally, simultaneous measurements of auroral currents, particle precipitation, convection and light emissions are required to establish these predictions. The data presented here are certainly suggestive that this mechanism is at work, however.

The electrons precipitating in the throat are cooler; the electrons precipitating away from noon are more energetic, and are associated with dayside arcs and strong field-aligned currents. It is possible that the cooler throat electrons have recently entered the magnetosphere directly by magnetic merging (Reiff et al., 1977), whereas the hotter, more structured auroral fan electrons have a more complicated history, probably entering diffusively, and are principally indicators of convection velocity shears rather than of direct injection from the magnetosheath.

Acknowledgments. We would like to thank S.-I. Akasofu for helpful discussions and the use of Figure 3. Parts of this work was supported by the Atmospheric Sciences section of the National Science Foundation, under grant ATM77-12619, and by the National Aeronautics and Space Administration under grants NGL44-004-130, NGL44-006-012, NGL44-006-137, and NAS8-32574.

References

Cassidy, R. T. Jr., and P. A. Cloutier, Rocket-based magnetic observations of auroral



Orbit 5960 1332UT May 10, 1975

Fig. 3. DMSP photograph of dayside auroral fan arcs. The cross indicates the south magnetic pole; the line points toward the sun. The afternoon side is on the right. (From Snyder and Akasofu, 1976). Note the similarity between the fan-like arc geometry and the convection pattern of Figure 2.

- Birkeland currents in association with a structured auroral arc, J. Geophys. Res., **80**, 2165-2168, 1975.
- Cauffman, D. P. and D. A. Gurnett, Satellite measurements of high-latitude convection electric fields, Space Sci. Rev., **13**, 369, 1972.
- Cogger, L. L., J. S. Murphree, S. Ismail, and C. D. Anger, Characteristics of dayside 5577 Å and 3914 Å aurora, Geophys. Res. Lett., **4**, 413-416, 1977.
- Dandekar, B. S. and C. P. Pike, Dayside auroral gap, (Abstract), FOS, Trans. AGU, **58**, 479, 1977.
- Gurnett, D. A. and L. A. Frank, Observed relationships between electric fields and auroral particle precipitation, J. Geophys. Res., **78**, 145-170, 1973.
- Heelis, R. A., W. B. Hanson, and J. L. Burch, Ion convection velocity reversals in the dayside cleft, J. Geophys. Res., **81**, 3803-3809, 1976.
- Heppner, J. P., Polar cap electric field distributions related to the interplanetary magnetic field direction, J. Geophys. Res., **77**, 4877-4887, 1972.
- Iijima, T. and T. A. Potemra, The amplitude distribution of field-aligned currents at northern high latitudes observed by Triad, J. Geophys. Res., **81**, 2165-2174, 1976a.
- Iijima, T. and T. A. Potemra, Field-aligned currents in the day-side cusp observed by Triad, J. Geophys. Res., **81**, 5971-5979, 1976b.
- Ismail, S., D. D. Wallis, and L. L. Cogger, Characteristics of polar cap sun-aligned arcs, J. Geophys. Res., **82**, 4741-4749, 1977.
- Kamide, Y., and S.-I. Akasofu, The location of the field-aligned currents with respect to discrete auroral arcs, J. Geophys. Res., **81**, 3999-4003, 1976.
- McDiarmid, I. B., J. R. Burrows, and E. E. Budzinski, Particle properties in the dayside cleft, J. Geophys. Res., **81**, 221-226, 1976.
- Meng, C.-I., and S.-I. Akasofu, The relation between the polar cap auroral arcs and the auroral oval arc, J. Geophys. Res., **81**, 4004-4006, 1976.
- Potemra, T. A., W. K. Peterson, J. P. Doering, C. O. Bostrom, R. W. McIntire and R. A. Hoffman, Low-energy particle observations in the dayside cusp from AE-C and AE-D, J. Geophys. Res., **82**, 4765-4776, 1977.
- Rees, M. E. and D. Luckey, Auroral electron energy derived from ratio of spectroscopic emissions: 1. Model computations, J. Geophys. Res., **79**, 5181-5186, 1974.
- Reiff, P. H., J. L. Burch and R. A. Heelis, Flow-aligned dayside auroral arcs, in Programme and Abstracts of the Second Magnetospheric Cleft Symposium, ed. J. R. Burrows, Amer. Geophys. Union, 1976.
- Reiff, P. H., T. W. Hill, and J. L. Burch, Solar wind plasma injection at the dayside magnetospheric cusp, J. Geophys. Res., **82**, 479-491, 1977.
- Riedler, W. and H. Borg, High-Latitude precipitation of low-energy particles as observed by ESRO IA, Space Research, **12**, 1397-1403, 1972.
- Kostoker, G. and R. Bostrom, Mechanism for driving the gross Birkeland current configuration in the auroral oval, J. Geophys. Res., **81**, 235-244, 1976.
- Sato, T., Field-aligned currents and polar cap electric fields, J. Geophys. Res., **81**, 263-264, 1976.
- Shepherd, C. G., F. W. Thirkettle, and C. D. Anger, Topside optical view of the dayside cleft aurora, Planet. Space Sci., **24**, 937, 1976.
- Snyder, A. L., Jr., and S.-I. Akasofu, Auroral oval photographs from the DMSP 8531 and 10533 satellites, J. Geophys. Res., **81**, 1799-1804, 1976.
- Wolf, R. A., Ionosphere-magnetosphere coupling, Space Sci. Rev., **17**, 537-562, 1975.
- Yasuhara, F. and S.-I. Akasofu, Field-aligned currents and ionospheric electric fields, J. Geophys. Res., **82**, 1279-1284, 1977.
- Yasuhara, F., Y. Kamide and S.-I. Akasofu, Field-aligned and ionospheric currents, Planet. Space Sci., **23**, 1355-1368, 1975.
- Zmuda, A. J. and J. C. Armstrong, The diurnal flow pattern of field-aligned currents, J. Geophys. Res., **79**, 4611-4619, 1974.

(Received January 9, 1978;
revised March 3, 1978;
accepted March 21, 1978.)

Comment on 'Correlated Electric Field and Low Energy Electron
Measurements in the Low Altitude Polar Cusp'
by P. M. Kintner, K. L. Ackerson, D. A. Gurnett, and L. A. Frank

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Kintner *et al* (1978) have noted the existence of two distinct types of relationships among the 5.2-keV electron trapping boundary, the equatorward edge of low-energy electron fluxes, and the convection electric-field reversal in the low-altitude polar cusp. The purpose of this comment is to point out that the two types of behavior are actually quite similar and are understandable in the context of a previous paper by Heelis *et al* (1976) if one assumes that in both of the examples presented by Kintner *et al*, Hawkeye 1 passed through or near a restricted MLT region within the cusp--the region through which the sunward flow at lower latitudes reverses and is channeled into the antisunward flow that fills the polar cap.

In the Heelis *et al* paper it was noted that the equatorward edge of the cusp was in all cases evidenced by a coincident increase in magnitude and variability of the ion convection measurements made on Atmosphere Explorer C (AE-C). This correspondence was so striking that it was stated therein that "...in all...orbits examined, a valid determination of the cusp equatorward boundary can be made just from the changes in the character of the horizontal drift velocity." It was further noted, however, that examination of the total vector ion drift velocity showed that changes at the cusp boundary do not always include a reversal of the east-west component of ion flow. This reversal in many cases occurred at significantly higher latitudes within the cusp, or not at all, when the flow simply took on a strong

antisunward component while maintaining the general direction of east-west flow that existed at lower latitudes. In those cases which did involve sharp reversals in the flow direction a coincident cusp equatorward boundary was always found. These reversals were called shear reversals by Heelis *et al*, and were interpreted as electric equipotentials bounding the cusp at its equatorward boundary. Cases which did not fit this pattern involved significant poleward convection across the cusp equatorward boundary as the flow vector rotated gradually along the satellite track through about 90°, from a generally sunward direction at lower latitudes to a generally antisunward direction in the polar cap. In these cases a clear flow reversal could not be identified, and the region traversed was interpreted as being connected to a region of the magnetopause across which magnetospheric plasma was flowing.

As noted in the Kintner *et al* (1978) paper, the data shown in their Figure 2 displays all the features that the Heelis *et al* (1976) paper associated with passes through a noontime region of rotational reversals (or convection "throat"). The convection velocity strengthened considerably and changed in direction between 20:55 and 20:56 UT--the time identified by Kintner *et al* as that at which the 5.2-keV trapping boundary and the cusp equatorward boundary were also crossed. In fact, the flow characteristics change quite dramatically a little after 20:56 UT which is the boundary we would associate with the low latitude edge of the cusp. This definition would seem to be acceptable

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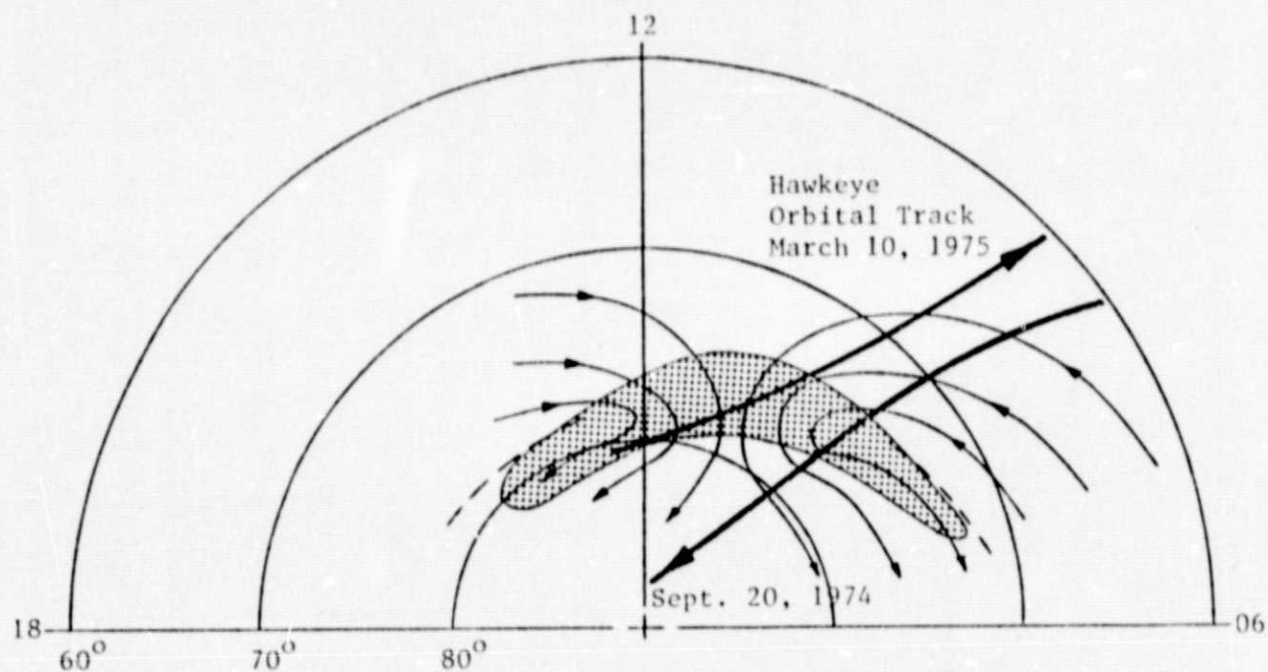


Figure 1. Schematic of suggested configuration in invariant latitude and magnetic local time of convective flow paths (light curves), cusp particle precipitation (shaded area), and convection reversals (dashed curves) for the two Hawkeye orbits discussed by Kintner *et al* (1978).

from the particle observation shown by Kintner *et al.* Moreover, as noted by Heelis *et al.* for similar cases, the flow velocity did not reverse abruptly through angles near 180° , but instead rotated gradually, attaining a significant anti-sunward component by about 20:55 UT, at a somewhat higher latitude within the cusp.

The second example of Kintner *et al.* (their Figure 5) is actually quite similar to the first. Here the spacecraft passed through the convection throat at slightly earlier local times and at a more acute angle. Figure 1 shows the orientation of the two passes used by Kintner *et al.* with respect to the convection geometry that we believe to have existed at the time. Again from the change in convection velocity signatures we would predict the low latitude edge of the cusp to be at 22:43 UT--a boundary which shows essentially the same particle signatures as the previous example of Kintner *et al.* The higher latitude reversal (at about 22:45 UT), similar to that observed in Kintner *et al.*'s divergence of the polar cap flow as it expands away from the convection "throat" (see Figure 1). The fact that the 5.2-keV trapping boundary extended to a few degrees poleward of the cusp equatorward boundary is consistent with the findings of McDiarmid *et al.* (1976) that on the average about half the latitudinal width of the cusp is on field lines showing trapped energetic electron pitch-angle distributions.

The results of the Heelis *et al.* (1976) paper would also predict that when Hawkeye 1 or other spacecraft traverse the cusp at local times away from the dayside convection throat, the cusp equatorward boundary will be found to coincide with an abrupt reversal of the east-west component of ion convection.

It should be noted that in the throat convection region, the nature of an observed electric field reversal is very dependent on the orientation of the spacecraft with respect to the convection geometry. In contrast to Kintner *et al.*, who caution the use of particle data to locate the boundary between closed dayside field lines and polar cap field lines, we caution the use of electric field reversals as an indication of this boundary.

Acknowledgments. This research was supported in part by the National Aeronautics and Space Administration under contract NAS8-32584 and under grant NSG-5214.

REFERENCES

- Heelis, R. A., W. B. Hanson, and J. L. Burch, Ion convection velocity reversals in the dayside cleft, *J. Geophys. Res.*, **81**, 3803, 1976.
- Kintner, P. M., K. L. Ackerson, D. A. Gurnett, and L. A. Frank, Correlated electric field and low-energy electron measurements in the low-altitude polar cusp, *J. Geophys. Res.*, **83**, 163, 1978.
- McDiarmid, I. B., J. R. Burrows, and E. E. Budzinski, Particle properties in the dayside cleft, *J. Geophys. Res.*, **81**, 221, 1976.

EFFECTS OF THE INTERPLANETARY MAGNETIC FIELD
ON THE AURORAL OVAL AND PLASMAPAUSE

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Submitted for publication in Space Science Reviews
Supported by NASA Grant NSG 5214

May 1978

Revised July 1978

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ABSTRACT

Recent research into the effects of the interplanetary magnetic field (IMF) on the earth's auroral oval and plasmapause are reviewed. While the IMF sector structure has been known for some time to produce asymmetries in polar-cap convection, recent work has shown these effects to extend into the dayside auroral oval. A restricted region of local times referred to as the convection "throat" is found to move to either side of the noon meridian in response to changes in the IMF B_y component.

The question of the entry of solar-wind plasma into the magnetosphere continues to be a prime area of research. While it is generally felt that magnetic merging must play some significant role, evidence continues to mount that it does not occur at the subsolar magnetopause, as previously supposed, and that other driving forces for antisunward convection must occur on closed field lines. A suggestion is made that many of the seemingly conflicting observations that have been made in the region of the dayside cusps can be explained if significant distortions of closed field lines near the dayside magnetopause are allowed and if closed and open field lines coexist in the cusp, particularly near the entry layer.

Effects of the IMF on the nightside auroral oval and on the plasmapause stem chiefly from the expansion of the oval to lower latitudes which is produced by southward IMF components and from the impulsive substorm phenomena that become stronger and more probable with increasingly southward IMF.

I. INTRODUCTION

This paper reviews and attempts to synthesize recent experimental results and theoretical models on the effects of the interplanetary magnetic field (IMF) on the earth's auroral oval and plasmopause. Quite a number of phenomena involving electric and magnetic fields, currents, plasmas, and auroral displays have been attributed to interactions between the IMF and the geomagnetic field. Progress until 1974 has been reviewed by Burch (1974) and Nishida (1975). Attention here will be focused on more recent work. Much of the recent progress has resulted from new data on near-earth field-aligned currents provided by the Triad satellite and on distant plasma flows by the HEOS satellite, from new analyses of older data from the ISIS 2 satellite, and from ground-based data taken at observatories such as the Chatanika radar. The IMF data for these studies have generally been obtained from the IMP series of satellites through the National Space Science Data Center.

The auroral oval, in its essence as the instantaneous locus of discrete visible auroras, is the region of near-earth space which experiences by far the greatest input of energy from the solar wind and the magnetosphere. Although the auroral oval is readily discernible near the earth, its extension into space is not understood. At higher latitudes the field lines of the polar cap are open, while the lower latitude field lines, extending through the diffuse aurora equatorward to the plasmopause, are closed. The auroral oval, on the other hand, is probably threaded by both types of field lines.

Field-aligned currents transfer energy from the solar wind and outer magnetosphere to the ionosphere through the auroral oval. These currents are produced in the conversion of closed field lines to open ones (and vice-versa) and in the reversal of plasma flows. The dayside of the auroral oval is the site of direct entry of solar wind plasma into the magnetosphere and of the generation of electric fields that drive plasma convection within it. The night side of the oval is a site of strong dissipation of energy that is temporarily stored in the magnetosphere. This dissipation occurs through substorms. Although substorms are not generally triggered by the IMF, their size and intensity is closely related to it.

The following sections begin with a discussion of phenomena that occur in the dayside auroral oval and proceed to considerations of night-side processes. These sections are followed by a brief discussion of plasmopause phenomena since their relationships with the IMF have not been the subject of intensive study.

II. EFFECTS OF THE IMF ON THE DAYSIDE AURORAL OVAL

A. Ionospheric Convection

At low and mid-altitudes (out several earth radii along magnetic field lines) the auroral oval is identified as the magnetospheric cusps or clefts within which plasmas of apparent magnetosheath origin are observed. Although localized acceleration of electrons occurs in the cusp, essentially unmodified magnetosheath positive-ion populations are observed at low altitudes over its entire 09 to 15 hr local-time width. This observation has led to a generally accepted belief that plasma enters the magnetosphere over the entire dayside magnetopause. However, recent measurements of magnetic and electric fields and of field-aligned currents in this region have shown the entry to be confined to a much narrower local-time sector which moves eastward and westward across the noon meridian in response to changes in the east-west component of the IMF.

The first hint of this localized entry region came from the HEOS magnetic-field measurements reported by Hedgecock and Thomas (1975). Reviewed recently by Fairfield (1977), the HEOS data showed the dayside magnetic-field vectors near the magnetopause to converge to a small region in a "cusp-like" rather than a "cleft-like" configuration. This discovery was followed closely by the findings of Heelis et al (1976) who used the convection velocity measurements of Atmosphere Explorer C to identify a narrow "throat" through which plasma is channeled in its reversal from sunward to antisunward convection. A conceptual diagram presented by

Fairfield (1977) combines the Heelis et al results with those of Heppner (1977) to suggest a possible convection pattern for the entire northern polar regions for conditions of positive IMF B_y ("away" sector). Fairfield's conceptual diagram is reproduced here as Figure 1. Confirmation of this displacement of the northern hemisphere "throat" toward dusk for positive IMF B_y has been indirectly confirmed by the ISIS 2 magnetic-field measurements of McDiarmid et al (1978a). It is expected from the asymmetries that exist in polar-cap convection (Heppner, 1972) that shifts in the opposite sense will be observed in the southern hemisphere. This expectation awaits experimental verification. The McDiarmid et al results are based on the concept that a westward magnetic-field perturbation in the northern hemisphere is produced by eastward convection, and vice-versa. This concept attributes a "line-tying" effect to the ionosphere in which Pederson currents dissipate energy at the feet of field lines, inhibiting plasma flow in the ionosphere. Having no effect at higher altitudes, this effect should result in an eastward tilt of eastward-convecting field lines and a westward tilt of westward-convecting field lines.

The clear separation found by McDiarmid et al (1978a) between eastward and westward convection signatures in the cusp is shown in Figure 2, which is reproduced from their paper. Evident in Figure 2 is a strong tendency for eastward convection to be observed in a cusp crossing when the IMF B_y component is positive, as one would expect if the throat were displaced westward, or to an afternoon location. This eastward flow

would tend to feed polar-cap flow that is enhanced on the morning side, as observed by Heppner (1972). Further investigations by McDiarmid et al (1978a) showed the eastward and westward convection signatures to become stronger as B_y increased (see Figure 3). The main effect of the IMF B_z component on the cusp region magnetic perturbations appeared to be a shift of the region of maximum ΔB to lower latitudes as IMF B_z became more negative (see Figure 4, taken from McDiarmid et al, 1978a). This behavior is consistent with that found for the cusp particle-precipitation region by Burch (1973).

B. Field-Aligned Currents

Related to the cusp-region magnetic perturbations analyzed by McDiarmid et al (1978a) are the cusp-region field-aligned currents observed by the Triad satellite and reported by Iijima and Potemra (1976). Iijima and Potemra noted a large-scale tendency for the cusp-region field-aligned currents to flow into the ionosphere in the post-noon sector and out of the ionosphere in the pre-noon sector, and suggested that these currents may represent an ionospheric diversion of the Chapman-Ferraro magnetopause current system. Investigating a possible relationship with the IMF B_z component, Iijima and Potemra observed the current intensity (as derived from the associated magnetic-field perturbations) to increase as IMF B_z became more negative (see Figure 5). McDiarmid et al (1978a) reported a tendency for their magnetic-field perturbations to become stronger for both high negative B_z and high positive B_z . Figure 5 shows, however, that the

Iijima and Potemra data did not extend into the high positive B_z region, so similar behavior may be shown by the cusp-region field-aligned currents.

C. Dayside Auroras

The first observations of dayside auroras by the DMSP satellites (Snyder and Akasofu, 1976) have also revealed clearly the existence of a cusp- or throat-like behavior as sketched in Figure 6, which is taken from a paper by Akasofu (1976). The absence of auroras in the throat region has been postulated by Reiff et al (1978) to be due to the absence of shear-type convective flow reversals of the kind observed by Heelis et al (1976) in regions of local time on either side of the throat. Such reversals generally require field-aligned currents to feed the associated divergent or convergent ionospheric Pederson currents, and these field-aligned currents are suggested by Reiff et al to be the ultimate source of the dayside auroras.

The region occupied by dayside auroras has been observed by Horwitz and Akasofu (1977) to move toward lower latitudes as IMF B_z becomes more negative. This behavior is expected from the similar movement of the cusp particle-precipitation and ΔB regions as noted above. Superimposed upon the IMF-induced latitudinal movement of the cusp is an effect due to substorm activity. As noted by Kamide et al (1976) for cusp particle precipitation and by Horwitz and Akasofu (1977) for the dayside aurora region, the cusp is displaced further equatorward as substorm

activity increases. An example of this behavior is provided in Figure 7, which is taken from Horwitz and Akasofu (1977). The data in Figure 7 show an extended period with nearly constant IMF B_z during which a period of substorm activity occurs. It is seen in Figure 7 that the increased activity is accompanied by an equatorward movement of dayside auroras of about 1° , compared to shifts of several degrees associated with strong IMF southward excursions.

D. Plasma Entry

The low-altitude particle measurements of Reiff et al (1977) and McDiarmid et al (1976) and the distant cusp and magnetopause plasma measurements of Scopke et al (1976) and Haerendel et al (1978) can be used to construct an overall model of dayside plasma entry. Interpretations of these various results have been in seeming conflict as discussed at length by Heikkila (1978), Heikkila and Block (1977) and Reiff et al (1978). These conflicting results generally center on the question of whether cusp field lines are open or closed. The following discussion attempts to resolve, at least partially, these disagreements.

Figure 8 is a schematic diagram of plasma entry processes in the noon meridian as presented by Haerendel et al (1978). Shown in Figure 8 are the magnetosheath (MS), the low-latitude boundary layer (LLBL), the higher latitude entry layer (EL) and the plasma mantle (PM). The conclusions of Haerendel et al are that efficient entry of magnetosheath plasma occurs in the cusp region, forming the entry layer. This efficient

entry proceeds through turbulent processes, probably including reconnection (or merging). The low-latitude boundary layer is populated by diffusive entry of magnetosheath plasma and/or by the energization of cold magnetospheric plasma that has been detached from the plasmasphere and has subsequently been convected to the region of the magnetopause.

It is suggested by Haerendel et al (1978) that enhanced merging at the cusp will result in dayside magnetic flux erosion (see Holzer and Slavin, 1978, and references therein) and a depletion of the low-latitude boundary layer. The plasma mantle is thought to be formed by the poleward convection of cusp plasma onto open field lines as it flows down to low altitudes and is magnetically mirrored to thence flow down the tail. Sckopke et al (1976) have demonstrated that the mantle thickness increases significantly (from $\sim 1 R_E$ to several R_E) when IMF B_z becomes strongly negative. This mantle thickening is easily understood in terms of enhanced poleward flow velocities resulting from the southward IMF, perhaps through increased merging at the cusp.

The HEOS results as summarized in Figure 8 lead, therefore, to a model in which the plasma mantle is purely on open field lines and the low-latitude boundary layer is purely on closed field lines, while the transition occurs through turbulent processes at the entry layer. The low-latitude measurements toward the flanks of the dayside magnetopause (Eastman et al, 1976) can also be understood in the context of Figure 8 if the low-latitude boundary layer plasma is convected with significant velocities

around to the night side. However, Haerendel et al (1978) have not ascertained a consistent flow direction in the noon sector of the low-latitude boundary layer.

Measurements in the low-altitude cusp pose other questions. The results of Reiff et al (1977) show the occasional appearance of positive-ion energy/latitude dispersion signatures (similar to those noted by Shelley et al, 1976), that are consistent with the formation of the plasma mantle by poleward convection in the cusp as described above. Simultaneously there existed evidence of rapid ion diffusion onto closed field lines equatorward of the cusp (perhaps the low-altitude signature of the low-latitude boundary layer of Figure 8). The sporadic occurrence of the positive-ion energy/latitude dispersion signature may be due to an as yet unconfirmed dependence on the IMF, and is likely to be due to its localization within the convection "throat" (Heelis et al, 1976).

An area of apparent discrepancy between low- and high-altitude measurements lies in the observation of trapped energetic-electron pitch-angle distributions in the low-altitude cusp (McDiarmid et al, 1976). McDiarmid et al noted that on the average about half the latitudinal width of the low-altitude cusp shows these trapped distributions, which indicate field-line closure. In all cases, however, the intensity of the energetic electron fluxes drop sharply at the equatorward boundary of the cusp. As the cusp is normally identified by the presence of low-energy protons, and since the energy/latitude dispersion signatures of Reiff et al (1977) extend to the cusp

equatorward boundary, the existence of closed field lines significantly poleward of the equatorward boundary would lead to closed field lines in the plasma mantle. Preliminary results of a study now underway using Atmosphere Explorer D data show agreement with the overall results of McDiarmid et al (1976). That is, on the average roughly half the cusp is on closed field lines. However, those cases which show a minimum overlap between cusp protons and trapped electron distributions are the same ones which exhibit strong energy/latitude dispersion signatures. Therefore, agreement of the low-altitude measurements with those made at high altitudes, and summarized in Figure 8 is expected to be closest in the region of the dayside convection "throat".

An idea presented recently by Johnson (1978) is consistent with the plasma entry model of Haerendel et al (1978) and with the boundary-layer convection-generator model of Eastman et al (1976). Johnson's hypothesis is that efficient plasma entry occurs in a limited local-time sector of the high-altitude cusps (presumably a region corresponding to the convection "throat"). The entry occurs there primarily because of the weak-field neutral-point magnetic configuration, and may proceed through turbulent processes such as merging. Once inside, where the plasma energy density dominates the local magnetic-field energy density, the plasma begins to flow in the antisunward direction as its prior history disposes it to do. Diffusion of this flowing plasma onto closed dayside field lines produces the antisunward-flowing boundary layer as observed by Eastman et al, while the plasma mantle is produced in the manner described above.

Johnson's (1978) ideas ascribe more importance to the role of the boundary-layer closed-field-line region in the generation of convection than do those of Haerendel et al (1978). Although Johnson's model naturally accommodates closed field lines in the low-altitude cusp it does not explain the north-south cusp convection asymmetries discussed above.

The sketch in Figure 9 is an attempt to show how closed cusp field lines may be distorted in such a way as to allow dayside convection "throats" in the northern and southern hemispheres which are displaced to opposite sides of the noon meridian. Figure 9 is a view from above the north pole of the earth, the magnetopause boundary layer, and a single field line. Although the field line is closed, it intersects the northern hemisphere ionosphere in a prenoon-sector convection "throat" and the southern hemisphere ionosphere in a postnoon-sector convection "throat". The field is distorted significantly only near the magnetopause. Assuming no distortion at the dawn-dusk meridian, such a configuration at the "throat" requires a prenoon-postnoon asymmetry in the sunward convection region in the same sense as the one that has been observed for antisunward convection. That is, for negative IMF B_y ("toward" sector) the northern-hemisphere convection "throat" would be located in the prenoon sector and both sunward and antisunward convection would be strongest in the post-noon sector. The opposite behavior would be observed in the southern hemisphere.

In Figure 9 a high-latitude turbulent entry region is indicated at the northern and southern cusps. If, as suggested by Haerendel et al (1978), merging occurs at the entry regions, then one would expect open field lines to be produced there. If plasma also enters closed field lines there, as suggested by Johnson (1978), there is the possibility that both closed and open field lines coexist in the entry-layer/cusp region. A coexistence of open and closed field lines in the cusp could be responsible for the highly structured cusp electron fluxes which led Maynard and Johnstone (1974) to propose a localized particle entry model as sketched in Figure 10. The mixture of open and closed field lines would also lead to small-scale structure in cusp electric fields, as is observed, and a spreading of the flow into the entire polar cap as the open field lines would be expected to have somewhat stronger poleward flow components while flow that is more nearly east-west would exist on the closed field lines. A mixture of open and closed field lines at the entry-layer/cusp interface can also explain the sharp decrease of energetic electron fluxes noted by McDiarmid et al (1976) to occur in all cases at the equatorward boundary of the low-altitude cusp. Returning to Figure 9 we note that, in addition to the closed field line shown, open field lines may also thread the turbulent entry regions. The subsequent flow histories of plasmas resident on these two types of field lines may be quite different.

III. EFFECTS OF THE IMF ON THE NIGHTSIDE AURORAL OVAL

The night side of the auroral oval is dominated by substorm phenomena. While these phenomena are affected strongly by IMF variations, it has been difficult to establish direct cause-effect relationships. For example, solar-wind shock waves produce magnetospheric compressions that often trigger substorms over wide local-time sectors. A number of studies, culminating in the recent work of Kokubun et al (1977) have established that magnetospheric compressions trigger substorms with a high probability only when the magnetosphere is in a metastable state that is associated with periods of southward IMF. Nevertheless, for most substorms the triggering process appears to be internal to the magnetosphere.

It is well established that the intensity and spatial extent of substorms increase with the amount of southward IMF flux impinging on the magnetosphere in the preceding period of a half hour or so. Recent results (Kamide et al, 1977) have shown further that the probability of occurrence of substorms also increases greatly with increasing southward IMF. In their study, Kamide et al used data from the Alaska meridian north-south chain of all-sky cameras in order to be able to detect both high-latitude substorms (along the "contracted" auroral oval) and lower latitude substorms (as registered by the AE index).

An earlier study by Kamide and Akasofu (1974) used magnetometer data from the Alaska chain to demonstrate that substorms which follow periods of southward IMF occur at lower latitudes, are more widespread in

latitude, and involve much larger total westward ionospheric currents. These effects are shown in Figure 11. Horwitz et al (1978) have obtained similar results on the expansion of the nightside oval using data from the Alaska magnetometer chain combined with meridian scans of the convection electric fields from the Chatanika radar. The Horwitz et al results are shown schematically in Figure 12. It is apparent from Figure 12 that in addition to an expansion of the auroral oval over its entire nightside sector, both northward and southward convection electric fields are intensified following southward transitions of IMF B_z .

Caan et al (1977) have performed a quantitative study which relates the magnitudes of auroral-zone magnetic bays which follow southward turnings of the IMF to the total southward IMF flux reaching the magnetosphere. The results of that study are reproduced in Figure 13. Much of the scatter in Figure 13 is undoubtedly due to the incomplete coverage of magnetometer stations and in the use of but a single magnetogram in deriving bay amplitude. In interpreting this data, Caan et al noted that the energy dissipated during substorms appears to come from the tail lobes, which act as reservoirs of stored magnetic energy. They concluded that the IMF may control the size of substorms by influencing the amount of stored tail flux available for utilization by substorms.

IV. EFFECTS OF THE IMF ON THE PLASMAPAUSE

As pointed out by Chen and Siscoe (1977), the IMF is expected to influence the dynamics of the plasmopause through its control of convection electric fields in the magnetosphere. Chen and Siscoe used the results of Burton et al (1975) to estimate the relationship between solar-wind electric fields and magnetospheric electric fields. Assuming a plasmasphere refill flux rate of $2 \times 10^8 \text{ cm}^{-3} \text{ s}^{-1}$ at 1000 km, and noting that refill proceeds for L values within the region of closed convective flow paths (the corotation region), Chen and Siscoe were able to provide estimates of typical plasmasphere "sizes" that fall into the range of experimental measurements. However, the strong erosions and compressions of the nightside plasmasphere that are associated with substorm activity would be expected to mask any one-to-one correspondence between IMF fluctuations and plasmapause positions.

Another substorm-related phenomenon that would be expected to have strong effects on the plasmapause are the intense ($\sim 3 \text{ km/s}$) sunward ion flows which develop in the high latitude trough in the evening local-time sector. Examples of these flows, which are the strongest observed at any latitude by the Atmosphere Explorer drift meter (Hanson et al, 1973), have been presented by Burch et al (1976). As discussed by Banks et al (1974), such strong flows are expected to enhance the production rate of molecular ions in the trough as observed by Taylor et al (1975).

Except during very quiet times, one would expect from the above discussion that short-term effects of the IMF on the plasmopause will be dominated by the more impulsive phenomena associated with substorms. On the other hand, the long-term behavior of the plasmopause and phenomena such as dawn-dusk and interhemispheric asymmetries in convective flow velocities and ion composition may well be predictable directly from IMF variations.

V. SUMMARY AND CONCLUSIONS

The sector structure of the IMF has been known for some time to produce asymmetries in polar-cap convection and the associated ionospheric current systems. Recent work has shown these effects to extend into the dayside auroral oval, where a restricted region of local times referred to as the convection "throat" is found to move to either side of the noon meridian in response to changes in the IMF B_y component.

The question of the entry of solar-wind plasma into the magnetosphere continues to be a prime area of research. While it is generally felt that magnetic merging must play some significant role, evidence continues to mount that it does not occur at the subsolar magnetopause, as previously supposed, and that other driving forces for antisunward convection must occur on closed field lines. Conflicting observations made in the region of the dayside cusps might be explained if significant interhemispheric distortions of closed field lines near the dayside magnetopause are allowed and if closed and open field lines coexist in the cusps, particularly near the entry layer.

Effects of the IMF on the nightside auroral oval and on the plasma-pause stem chiefly from the expansion of the oval to lower latitudes that is produced by southward IMF components and from the impulsive substorm phenomena that become stronger and more probable with increasingly southward IMF.

REFERENCES

- Akasofu, S. -I.:1976, Recent progress in studies of DMSP auroral photographs, Space Science Rev., 19, 169.
- Banks, P.M., Schunck, R. W., and Raitt, W. J.:1974, NO^+ and O^+ in the high-latitude F-region, Geophys. Res. Lett., 1, 239.
- Burch, J. L.:1974, Observations of interactions between interplanetary and geomagnetic fields, Rev. Geophys. Space Phys., 12, 363.
- Burch, J. L., Fields, S. A., and Heelis, R. A.:1976, Substorm effects observed in the auroral plasma, in Physics of Solar Planetary Environments, ed. by D. J. Williams, American Geophysical Union, pp. 740-759.
- Burton, R. K., McPherron, R. L., and Russell, C. T.:1975, The terrestrial magnetosphere: A half-wave rectifier of the interplanetary electric field, Science, 189, 717.
- Caan, M. N., McPherron, R. L., and Russell, C. T.:1977, Characteristics of the association between the interplanetary magnetic field and substorms, J. Geophys. Res., 82, 4837.
- Chen, C. -K., and Siscoe, G. L.:1977, A method for finding plasmasphere statistics from solar wind measurements, J. Geophys. Res., 82, 1158.
- Eastman, T. E., Hones, E. W., Jr., Bame, S. J., and Asbridge, J.R.:1976, The magnetospheric boundary layer: Site of plasma, momentum, and energy transfer from the magnetosheath into the magnetosphere, Geophys. Res. Lett., 3, 685.

- Fairfield, D. H.:1977, Electric and magnetic fields in the high-latitude magnetosphere, Rev. Geophys. Space Phys., 15, 285.
- Haerendel, G., Paschmann, G., Sckopke, N., Rosenbauer, H., and Hedgecock, P. C.:1978, The front side boundary layer of the magnetosphere and the problem of reconnection, submitted to J. Geophys. Res.
- Hanson, W. B., Zuccaro, D. R., Lippincott, C. R., Sanatani, S.:1973, The retarding potential analyzer on Atmosphere Explorer, Radio Sci., 8, 333.
- Hedgecock, P. C., and Thomas, B. T.:1975, Heos observations of the configuration of the magnetosphere, Geophys. J. Roy. Astron. Soc., 41, 391.
- Heelis, R. A., Hanson, W. B., and Burch, J. L.:1976, Ion convection velocity reversals in the dayside cleft, J. Geophys. Res., 81, 3803.
- Heikkila, W. J., and Block, L. P.:1977, Review of magnetospheric boundary layer phenomena and their relation to current theories, Geophysica, 14, 165.
- Heikkila, W. J.:1978, Comment on "Solar wind plasma injection at the dayside magnetospheric cusp", by P. H. Reiff, T. W. Hill, and J. L. Burch, J. Geophys. Res., 83, 227.
- Heppner, J. P.:1972, Electric fields in the magnetosphere, in Critical Problems of Magnetospheric Physics, edited by E. R. Dyer, pp. 107-122, National Academy of Science, Washington, D.C.

- Heppner, J. P.:1977, Empirical models of high-latitude electric fields, J. Geophys. Res., 82, 115.
- Holzer, R. E., and Slavin, J. A.:1978, Magnetic flux transfer associated with expansions and contractions of the dayside magnetosphere, in press, J. Geophys. Res.
- Horwitz, J. L., and Akasofu, S. -I.:1977, Response of the dayside aurora to sharp northward and southward transitions of the interplanetary magnetic field and to magnetospheric substorms, J. Geophys. Res., 82, 2723.
- Horwitz, J. L., Doupnik, J. R., Banks, P. M., Kamide, Y., and Akasofu, S. -I.:1978, The latitudinal distributions of auroral zone electric fields and ground magnetic perturbations and their response to variations in the interplanetary magnetic field, J. Geophys. Res., 83, 2071.
- Iijima, T., and Potemra, T. A.:1976, Field-aligned currents in the dayside cusp observed by Triad, J. Geophys. Res., 81, 5971.
- Johnson, F. S.:1978, The driving force for magnetospheric convection, Rev. Geophys. Space Phys., 16, 161.
- Kamide, Y., and Akasofu, S. -I.:1974, Latitudinal cross section of the auroral electrojet and its relation to the interplanetary magnetic field polarity, J. Geophys. Res., 79, 3755.
- Kamide, Y., Burch, J. L., Winningham, J. D., and Akasofu, S. -I.:1976, Dependence of the latitude of the cleft on the interplanetary magnetic field and substorm activity, J. Geophys. Res., 81, 698.

- Kamide, Y., Perreault, P. D., Akasofu, S. -I., and Winningham, J. D.:1977, Dependence of substorm occurrence probability on the interplanetary magnetic field and on the size of the auroral oval, J. Geophys. Res., 82, 5521.
- Kokubun, S., McPherron, R. L., and Russell, C. T.:1977, Triggering of substorms by solar wind discontinuities, J. Geophys. Res., 82, 74.
- McDiarmid, I. B., Burrows, J. R., and Budzinski, E. E.:1976, Particle properties in the dayside cleft, J. Geophys. Res., 81, 221.
- McDiarmid, I. B., Burrows, J. R., and Wilson, M. D.:1978a, Magnetic field perturbations in the dayside cleft and their relationship to the IMF, in press, J. Geophys. Res.
- McDiarmid, I. B., Burrows, J. R., and Wilson, M. D.:1978b, Comparison of magnetic field perturbations at high latitudes with charged particle and IMF measurements, J. Geophys. Res., 83, 681.
- Maynard, N. C., and Johnstone, A. D.:1974, High-latitude dayside electric field and particle measurements, J. Geophys. Res., 79, 3111.
- Nishida, A.:1975, Interplanetary field effect on the magnetosphere, Space Science Rev., 17, 353.
- Reiff, P. H., Hill, T. W., and Burch, J. L.:1977, Solar wind plasma injection at the dayside magnetospheric cusp, J. Geophys. Res., 82, 479.
- Reiff, P. H., Hill, T. W., and Burch, J. L.:1978, Reply, J. Geophys. Res., 83, 229.

22
Sckopke, N., Paschmann, G., Rosenbauer, H., and Fairfield, D. H.:1976,

Influence of the interplanetary magnetic field on the occurrence and thickness of the plasma mantle, J. Geophys. Res., 81, 2687.

Shelley, E. G., Sharp, R. D., and Johnson, R. G.:1976, He^+ and H^+

flux measurements in the dayside cusp:Estimates of convection electric field, J. Geophys. Res., 81, 2363.

Snyder, A. L., Jr., and Akasofu, S. -I.:1976, Auroral oval photographs

from DMSP 8531 and 10533 satellites, J. Geophys. Res., 81, 1799.

Taylor, H. A., Jr., Grebowsky, J. M., and Chen, A. J.:1975, Ion composition irregularities and ionosphere-plasmasphere coupling:

Observations of a high latitude trough, J. Atmos. Terr. Phys. 37, 613.

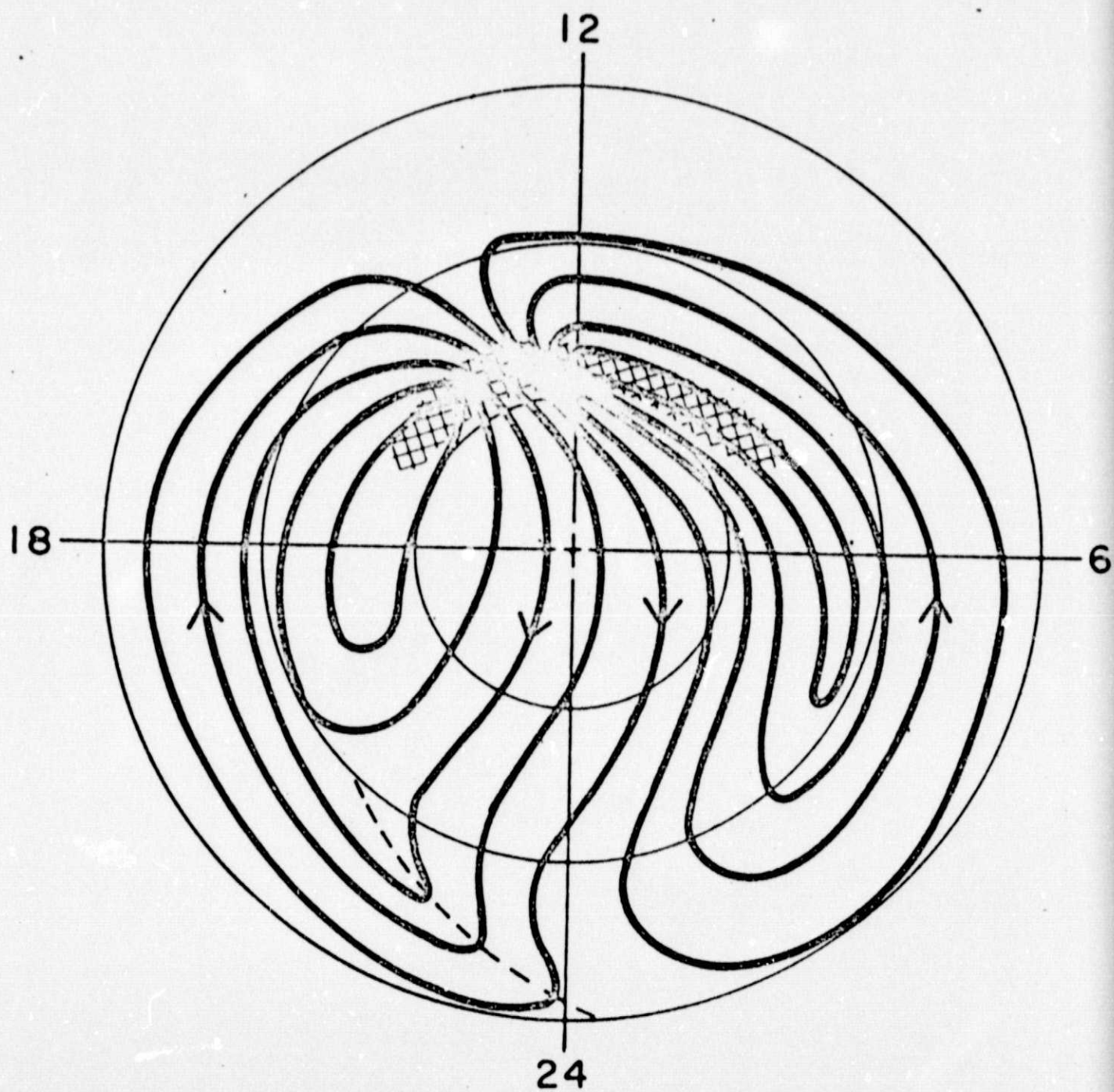


FIGURE 1.

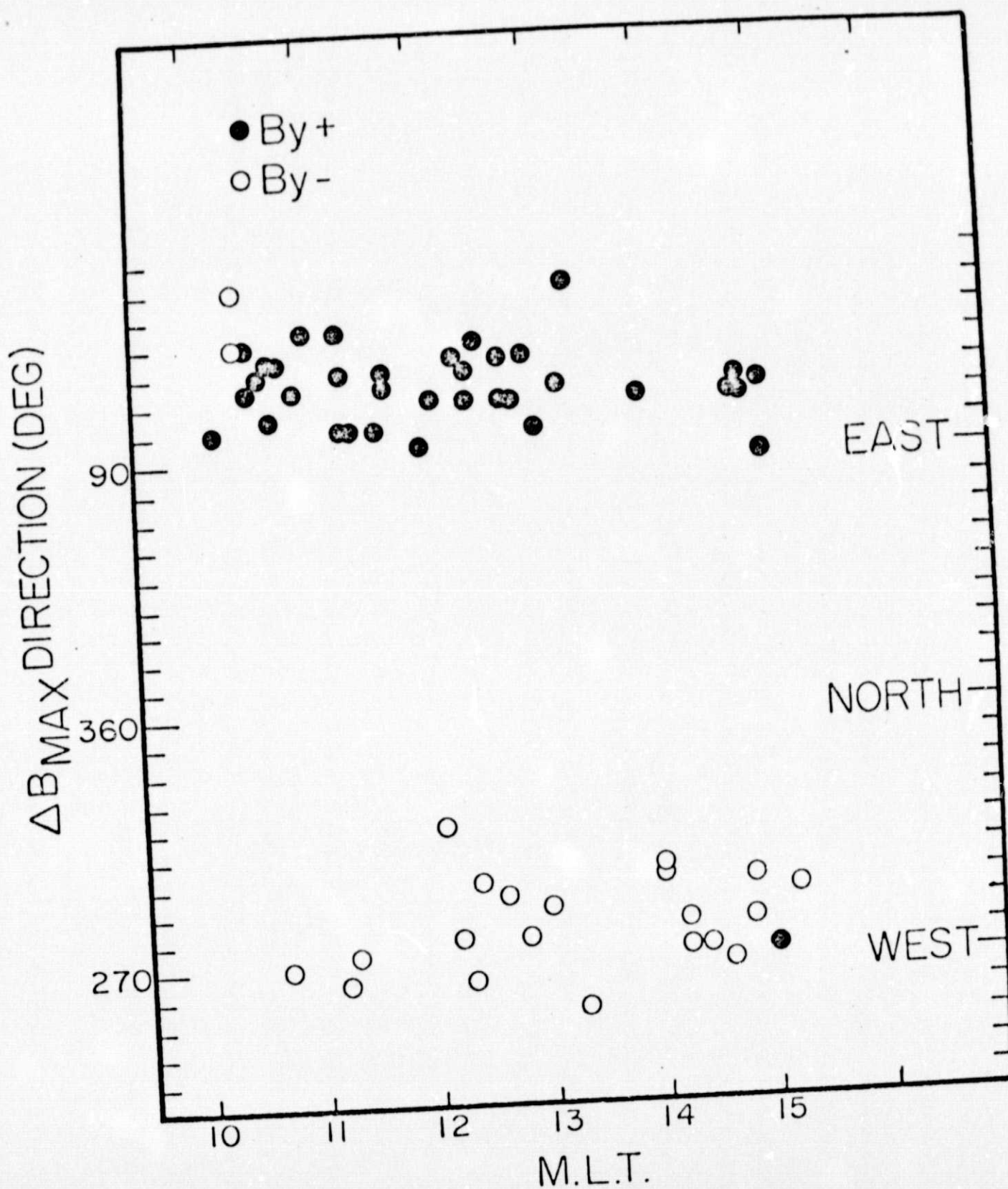
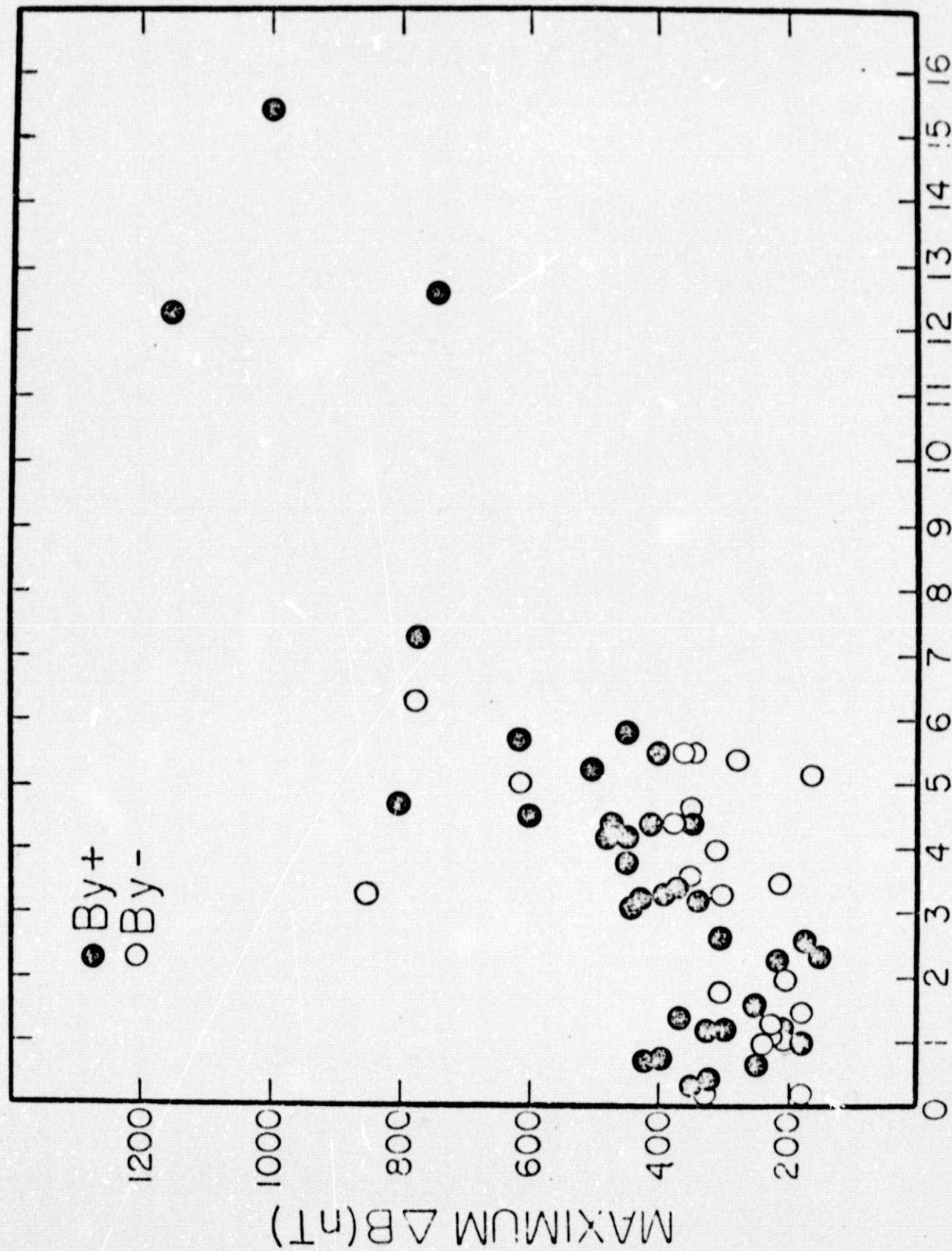


FIGURE 2.



By (IMF)

FIGURE 3.

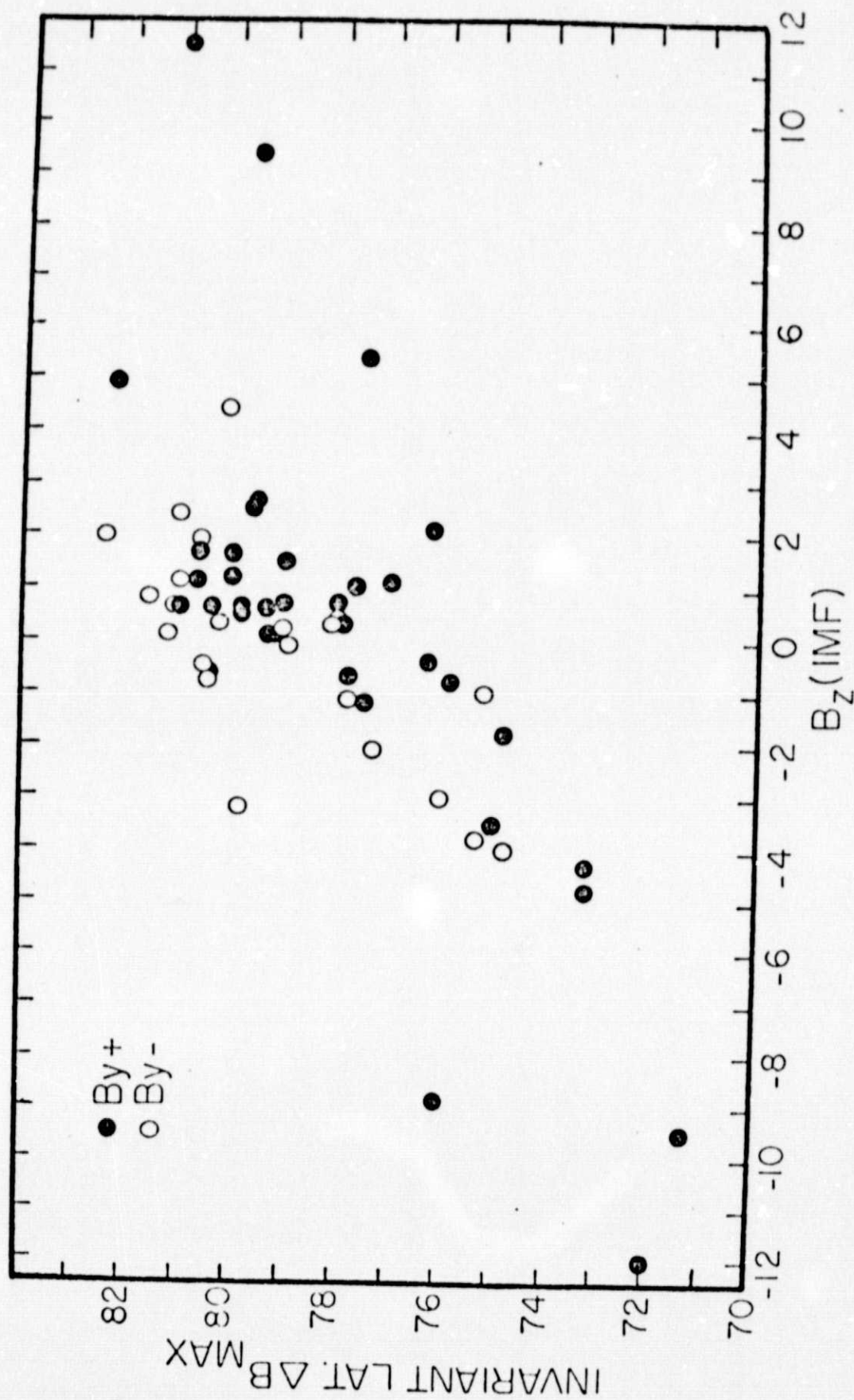


FIGURE 4.

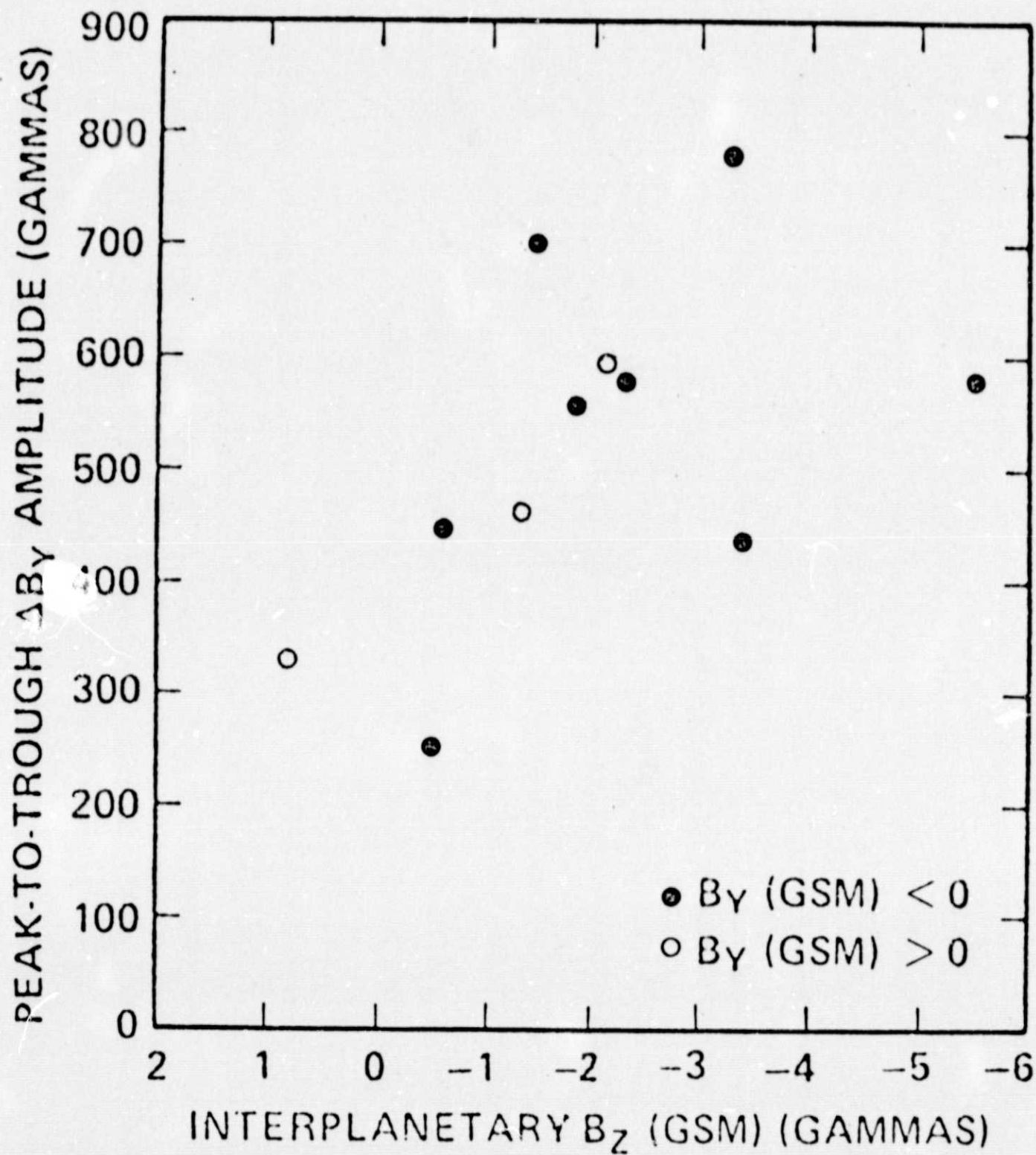


FIGURE 5.

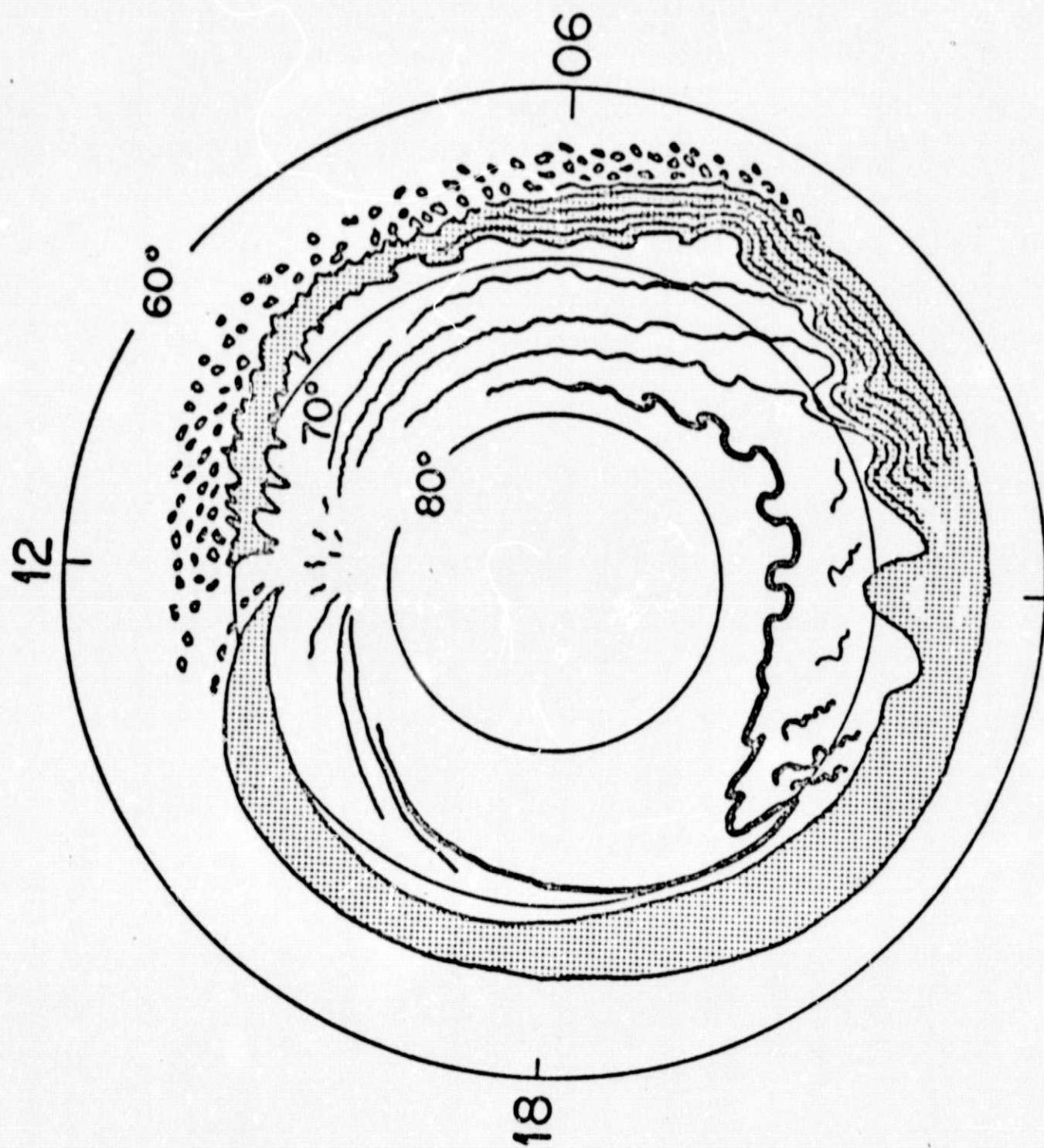
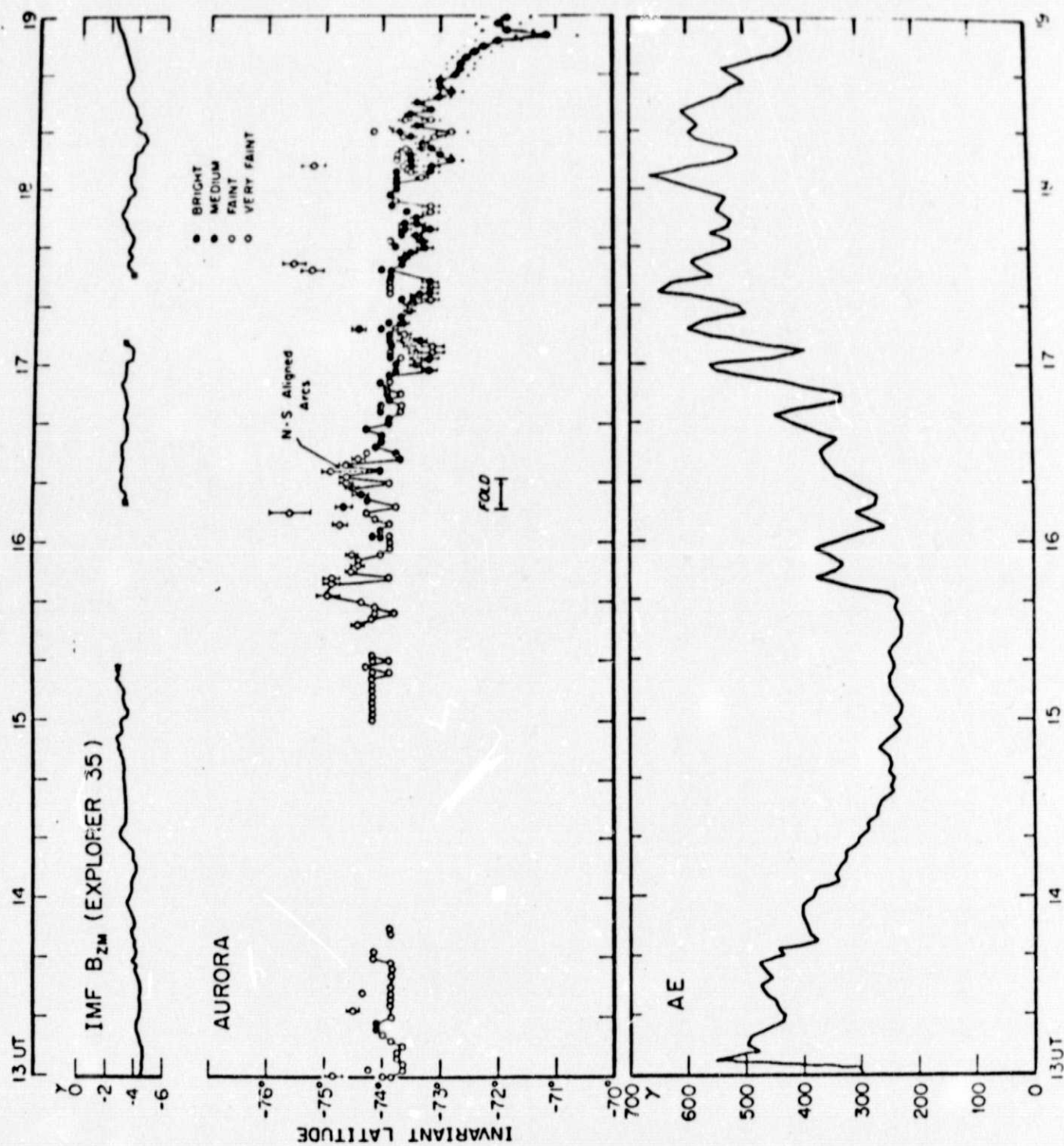


FIGURE 6.



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FIGURE 7.

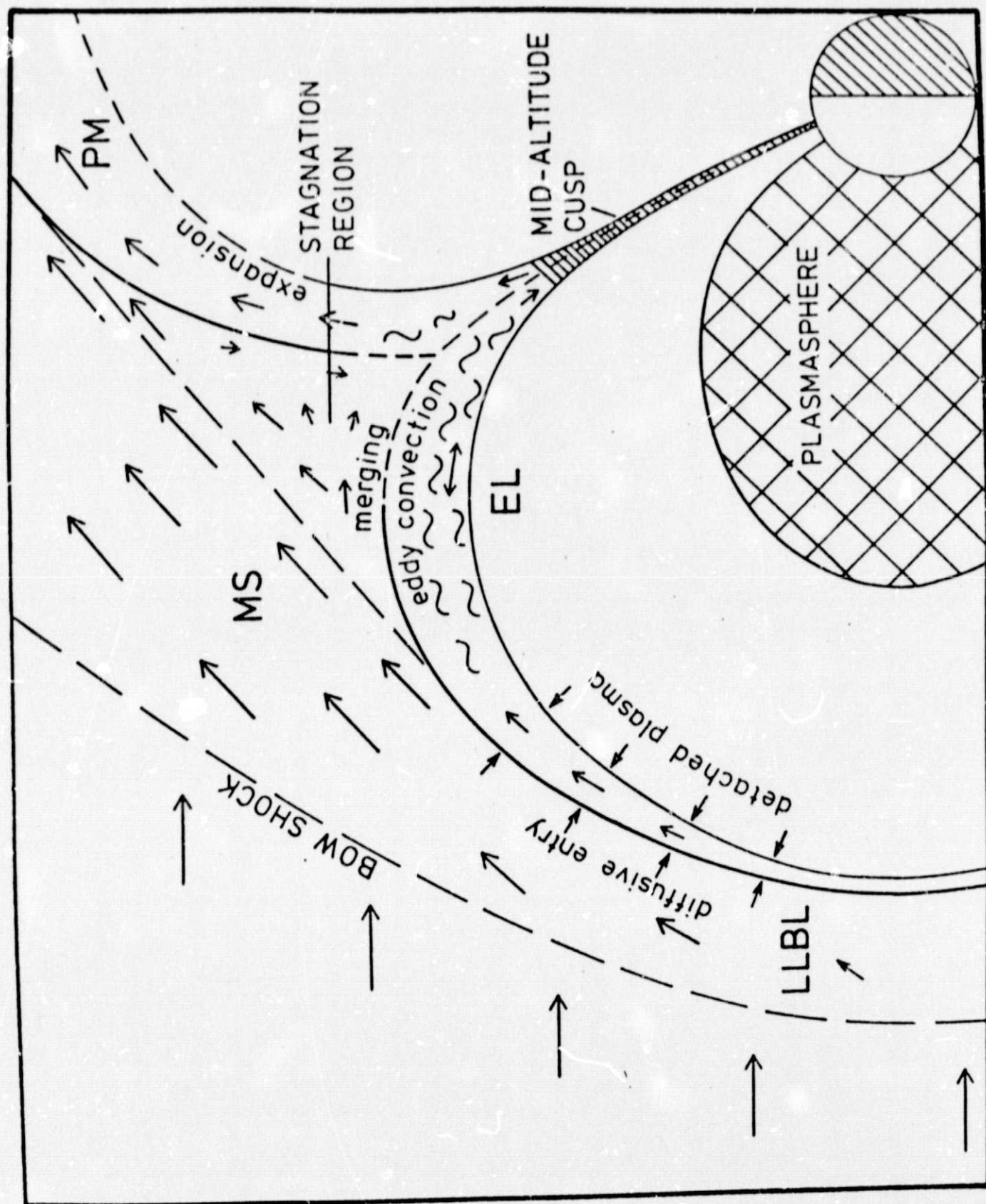


FIGURE 8.

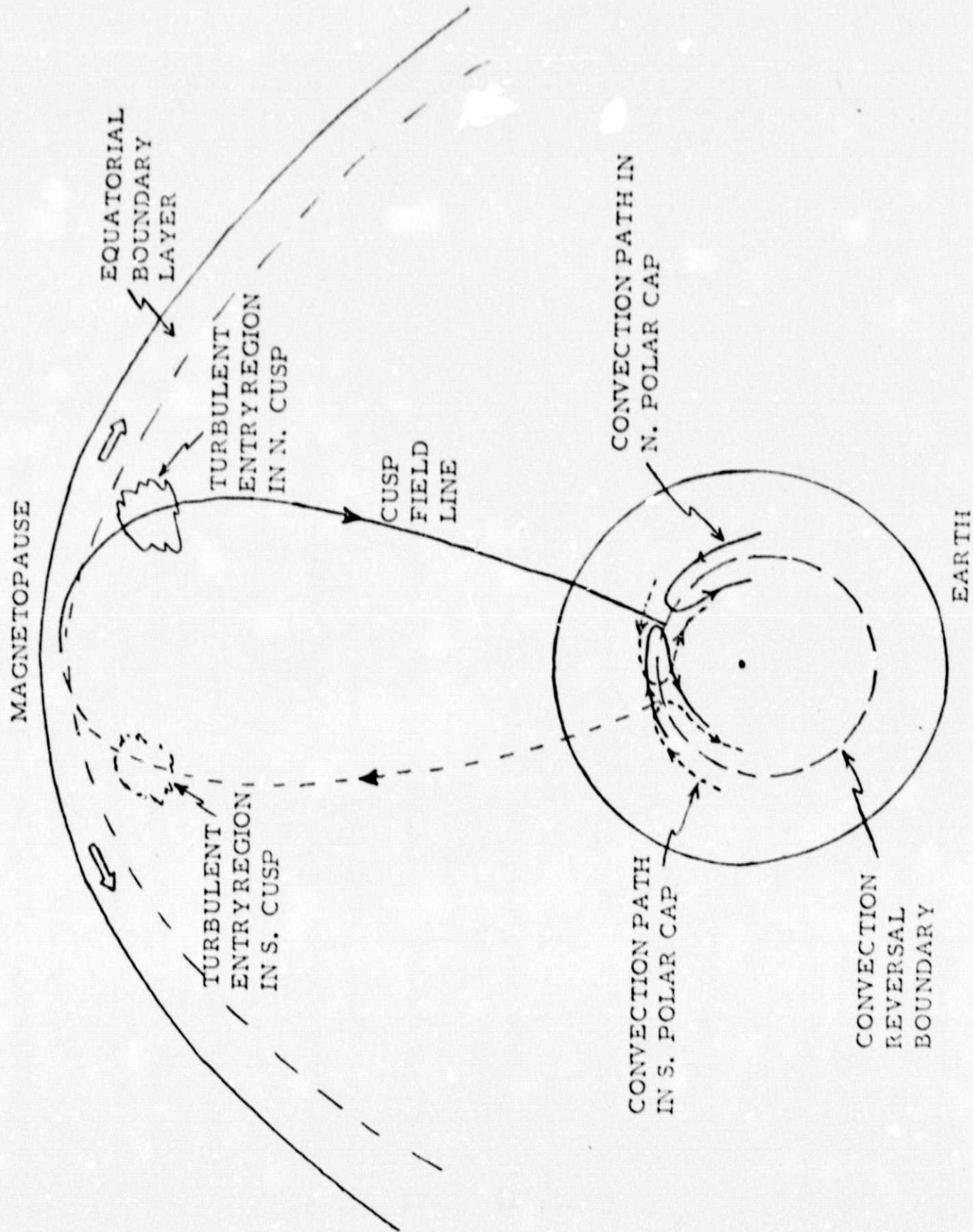


FIGURE 9.

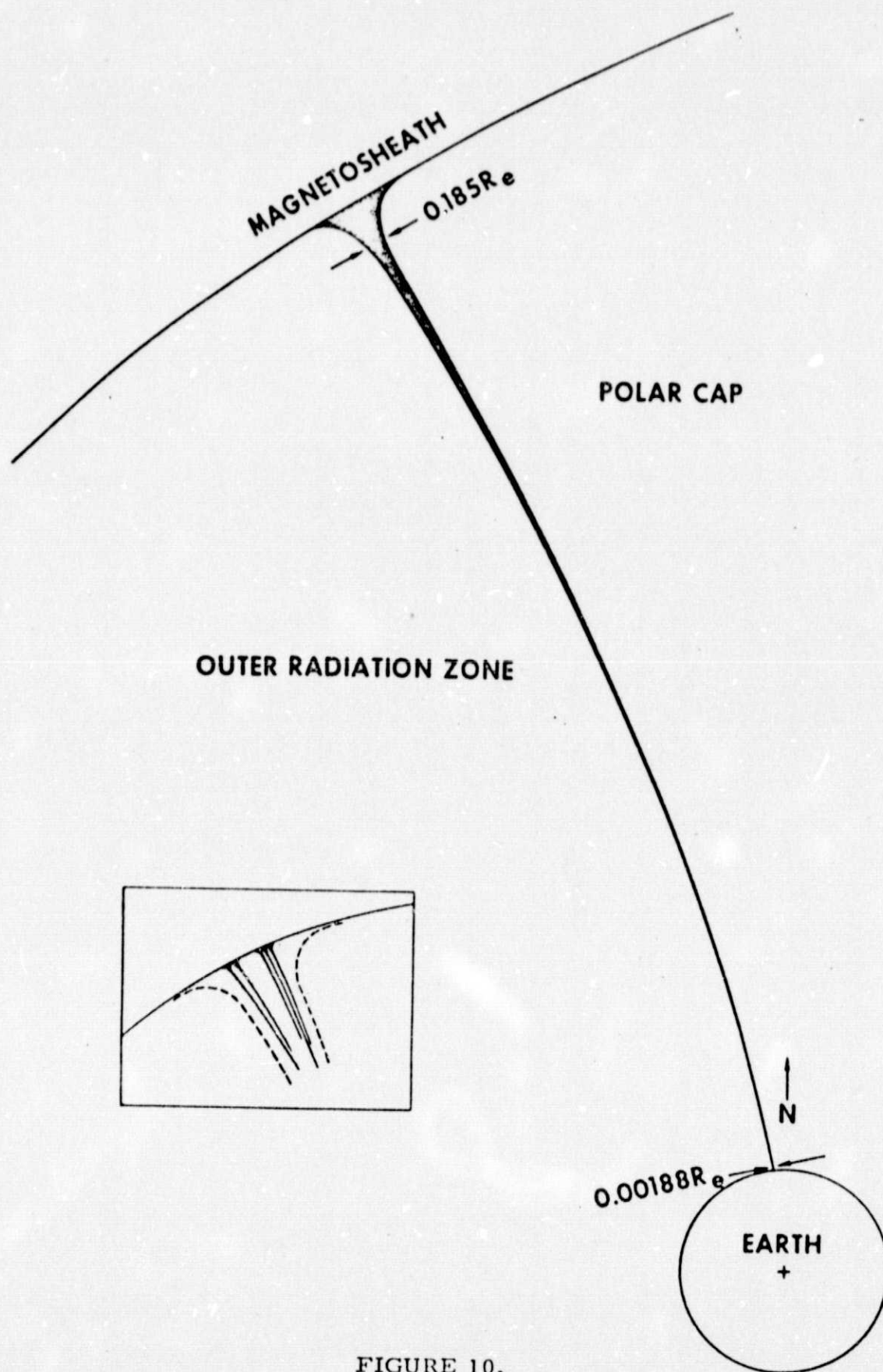
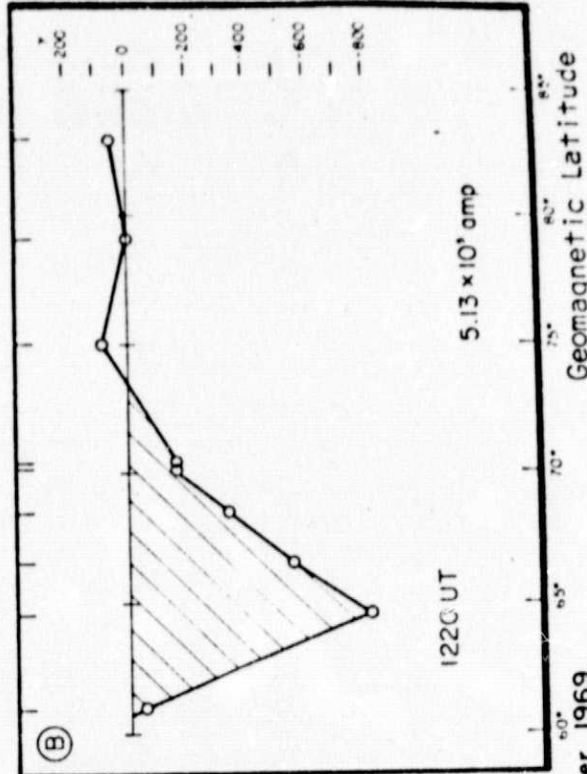
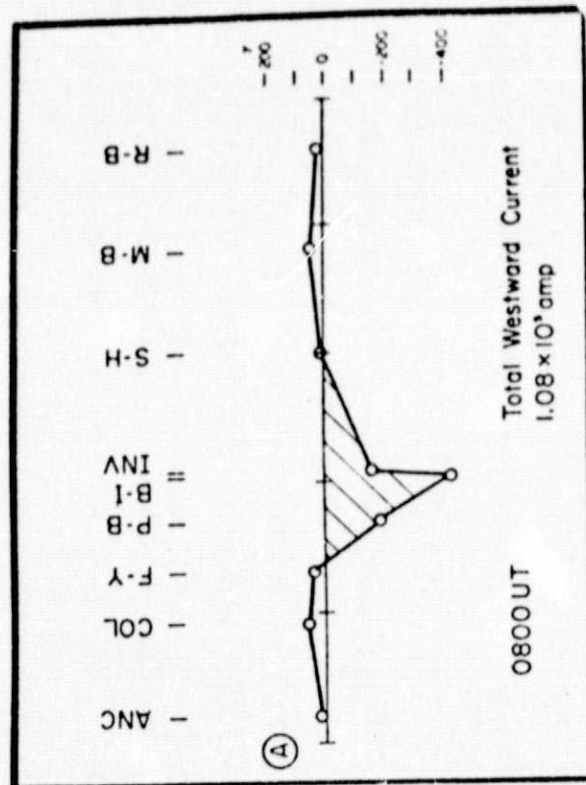
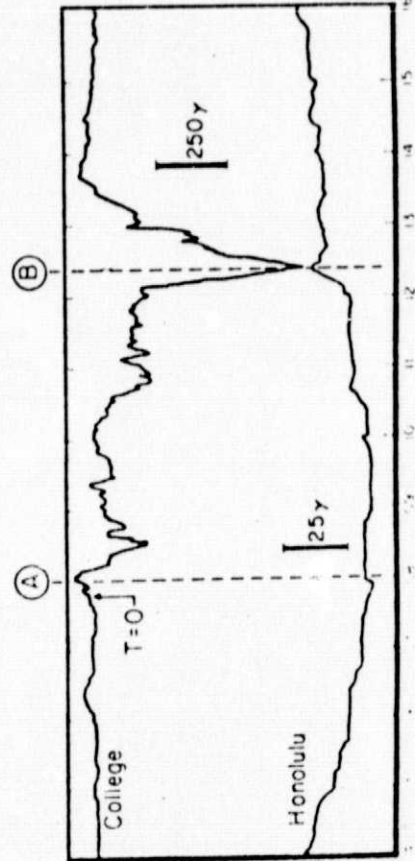
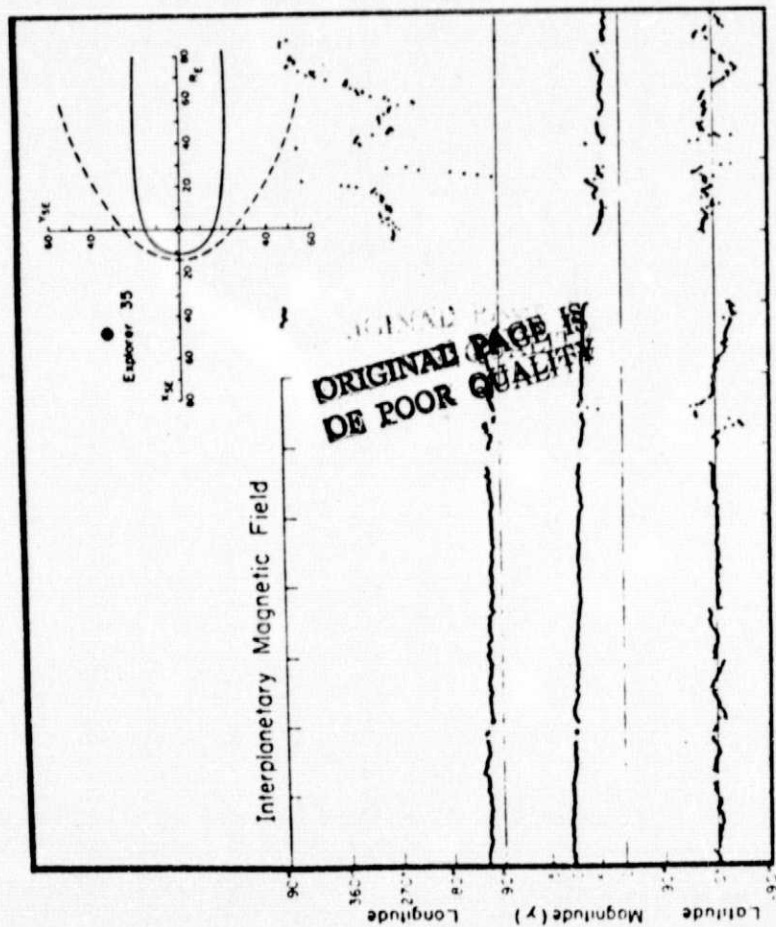


FIGURE 10.



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FIGURE 11.

INFLUENCE OF INTERPLANETARY MAGNETIC FIELD UPON E_L AND ΔH PATTERNS

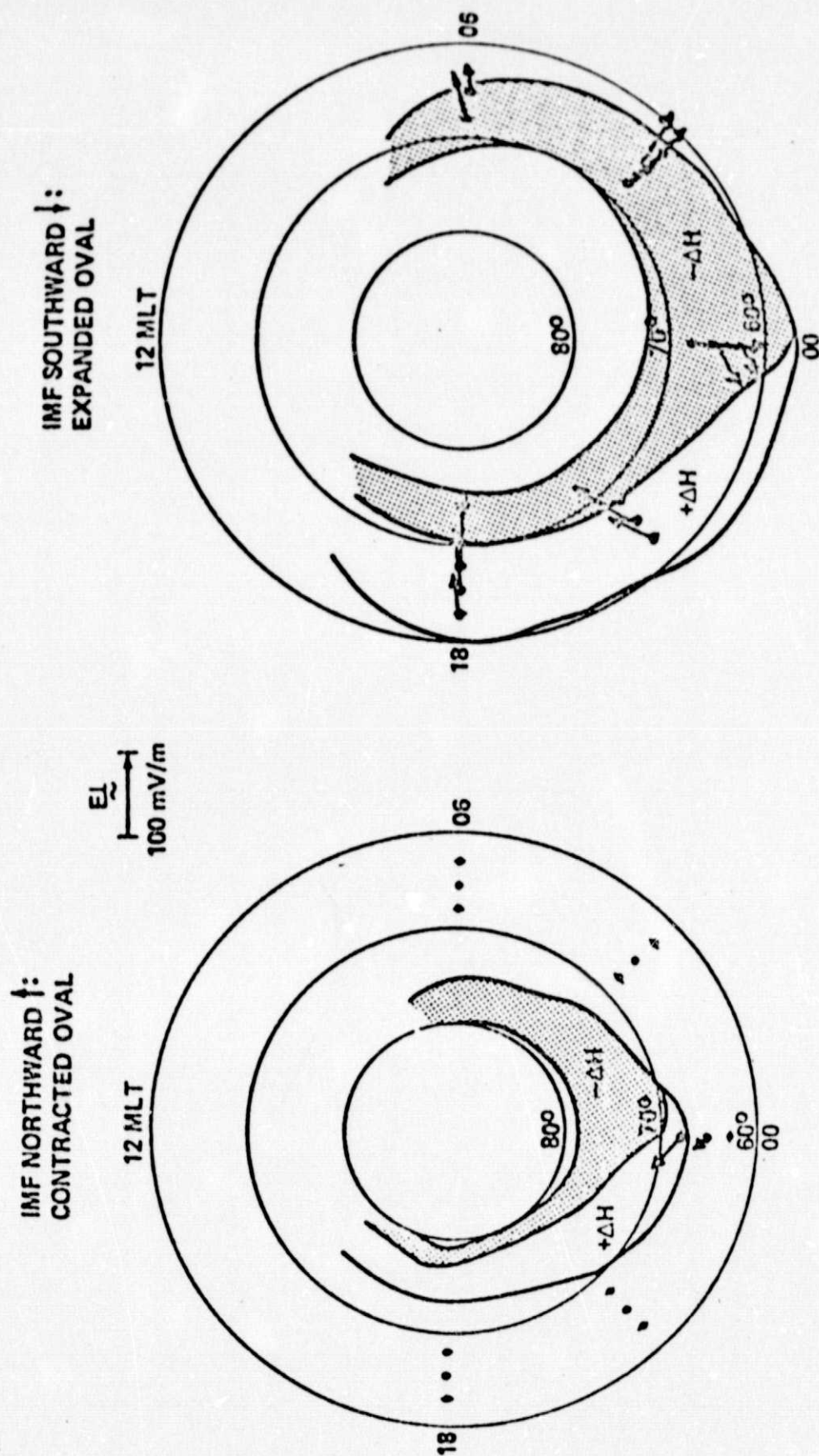
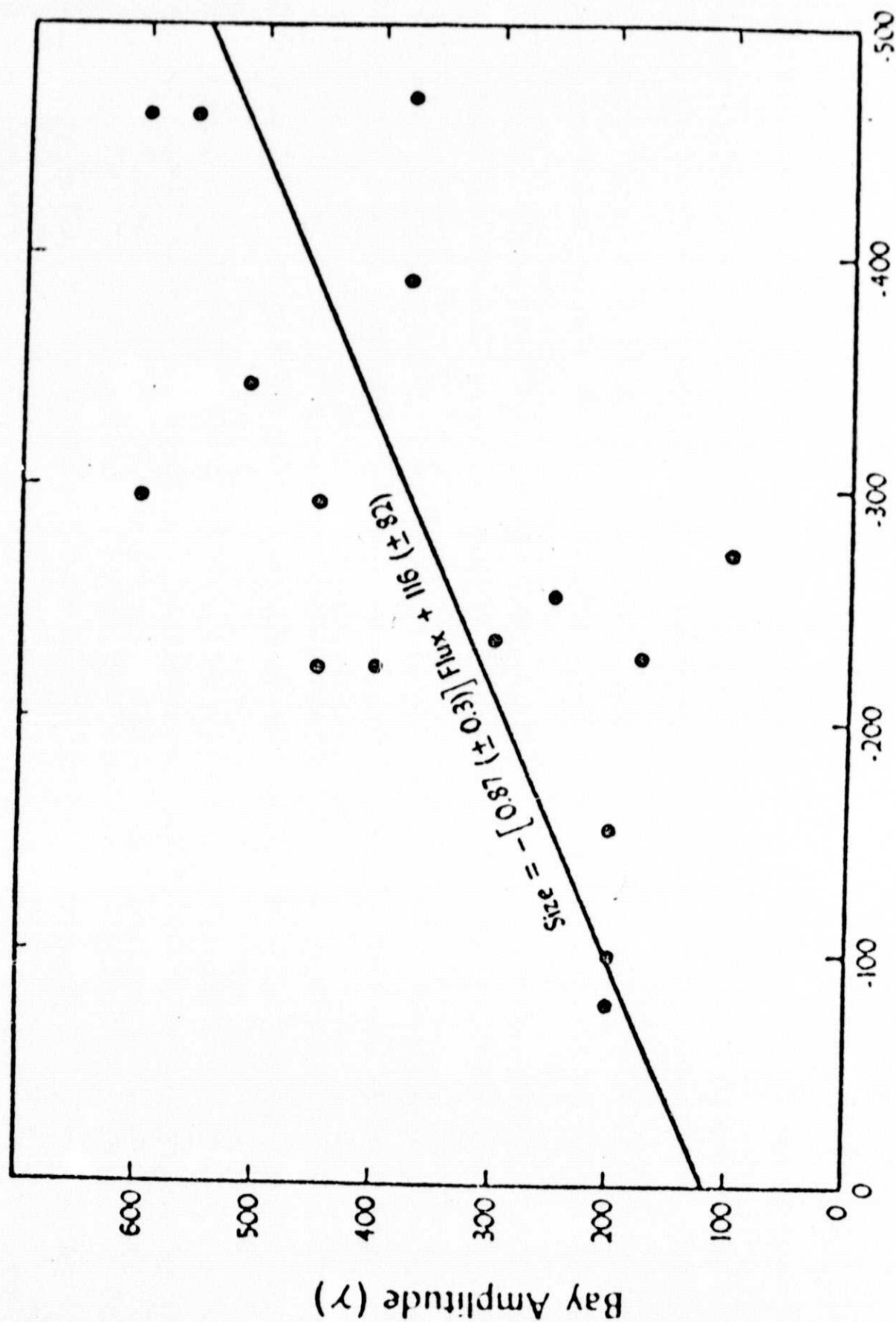


FIGURE 12.



Preceding IMF Flux ($\gamma - \text{min.}$)

FIGURE 13.